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Department of Agriculture, Stock and Fisheries,
Port Moresby

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Commencing with Volume 9, No. 1, *The Papua and New Guinea Agricultural Journal* will be the title for the former publication *Papua and New Guinea Agricultural Gazette.* The publication will still follow the form of the pre-war *New Guinea Agricultural Gazette* and will deal with recent advancement in tropical agriculture and act as an extension medium for the dissemination of agricultural information to the Territory planting and farming community.

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COMMONWEALTH OF AUSTRALIA

TERRITORY OF PAPUA AND NEW GUINEA

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Administrator :
Brigadier D. M. Cleland, C.B.E.

Director of Agriculture, Stock and Fisheries :
F. C. Henderson, Esq., B.Sc. Agr.

The
Papua and New Guinea
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Volume 3, Numbers 1 and 2.
Volume 4, Numbers 1, 2, 3 and 4.
Volume 5, Numbers 1, 2 and 3.
Volume 6, Numbers 1, 2 and 3.
Volume 7, Numbers 1, 2, 3 and 4.

The Papua and New Guinea Agricultural Gazette—

Volume 8, Numbers 1, 2, 3 and 4.

The Papua and New Guinea Agricultural Journal—

Volume 9, Numbers 1, 2, 3 and 4.
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Copies of all numbers of the *Gazette* to Volume 7, No. 4, are out of print.

DEATH OF DIRECTOR OF AGRICULTURE, MR. R. E. P. DWYER

THE Director of Agriculture, Stock and Fisheries of the Territory of Papua and New Guinea from 1952, Mr. R. E. P. Dwyer, died in Sydney on 3rd October, 1959. He was 57.

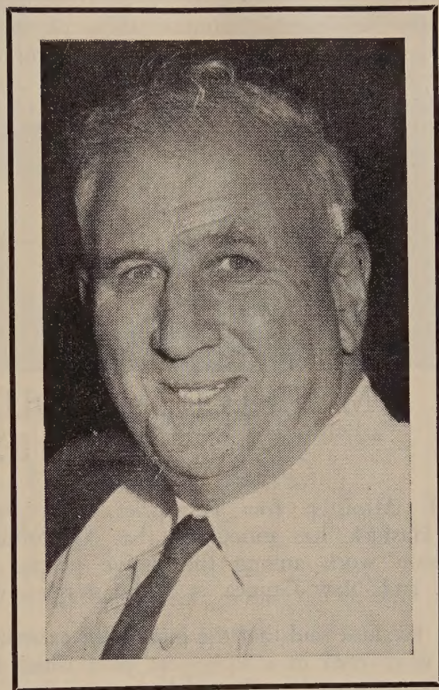
He has been succeeded by the former Chief of Division of Plant Industry, Mr. F. C. Henderson, whose appointment was announced by the Minister for Territories, Mr. Paul Hasluck.

The late Mr. Dwyer was one of the best known and most popular people in the Territory of Papua and New Guinea and his death is a loss to his many friends and to the Administration.

Mr. Dwyer began his agricultural career as an experimentalist in the New South Wales Department of Agriculture, after taking Diplomas in Agriculture and in Dairy Science from Hawkesbury Agricultural College. As a Cadet of the New South Wales Department, he attended Sydney University from 1923 to 1926, where he obtained his Bachelor of Science in Agriculture in 1927. Mr. Dwyer then worked as a Plant Breeder with the New South Wales Department and made valuable contributions in improving lucerne and oats.

In 1934 he was appointed Economic Botanist in the Department of Agriculture of the Mandated Territory of New Guinea, but before taking up active duties in the Territory he spent eight months in Java and Malaya studying tropical agriculture.

During his early years in the New Guinea service, Mr. Dwyer travelled widely and carried out a number of comprehensive surveys of the main plantation industries in the Territory. He published a series of technical articles on the major crops in New Guinea. His work on coconuts was outstanding and his publications on this crop are still well known throughout the tropical world. In 1937 he made a survey of the rubber industry in Papua on behalf of the Papuan Administration.



Mr. R. E. P. Dwyer

Escape from New Britain

At the outbreak of war he joined the New Guinea Volunteer Rifles and was with the unit when the Japanese landed in Rabaul. Mr. Dwyer escaped from Rabaul and walked across to the north coast of New Britain, where he contacted Mr. J. K. McCarthy's party and was evacuated in the *Lakatoi* with the survivors of the Rabaul Garrison. On his return to Australia he was released from the Army to carry out investigations of potential rubber-producing plants in the Charters Towers district. He then became a member of the Australian-New Guinea Production Control Board, an ANGAU organization which was responsible for controlling agricultural production in Papua and New

Guinea during the war. Later he was appointed an adviser to the Commonwealth Government of Papua and New Guinea war damage claims.

In the early postwar years, working in collaboration with the late Mr. J. B. McAdam and others, a resources survey was produced which was a useful background paper for the planning of postwar Administration activities.

In 1946, Mr. Dwyer took up an appointment with the provisional Administration of Papua and New Guinea as Economic Botanist and was later promoted to Chief of Division of Agricultural Extension. He became Director of the Department of Agriculture, Stock and Fisheries in 1952.

In 1950, Mr. Dwyer was appointed a Member of the Executive Council, and became a Member of the Legislative Council in 1952.

Mr. Dwyer was also a member of a number of Boards including the Copra Marketing Board, Copra Industry Stabilization Board and the Land Board.

During his career in the Territory the late Mr. Dwyer made a major contribution not only to the development of our primary industries, but also to general Administration policies. He will long be remembered for his kindliness and courtesy to all who had dealings with him.

Mr. Dwyer is survived by his widow and two daughters, aged 20 and 13.

MINISTER ANNOUNCES MAJOR INCREASE IN EXTENSION

THE Minister for Territories, Mr. Paul Hasluck, has announced that Agricultural Extension work among the native people of Papua and New Guinea is to be stepped up.

Mr. Hasluck said that the intensified extension work is covered in a three-year plan which he recently approved and which is designed to build up the field strength of the Division of Extension of the Department of Agriculture, Stock and Fisheries.

An extra 74 European officers are to be recruited and the force of native agricultural assistants is to be built up from the present 180 to about 300. This will give one agricultural fieldworker to about 5,000 of the rural population. In addition about 1,000 native farmers are to be trained each year in improved agricultural practices.

The plan also calls for the establishment of 22 additional agricultural extension centres from which field staff can work and at which agricultural demonstrations can be conducted and the more intensive use of extension aids such as film strips and the production of pamphlets. These aids will cover the more important aspects of crop growing and processing.

There will also be an increase in the amount of agricultural patrolling to provide a greater degree of contact with the agricultural population.

Mr. Hasluck predicted that as a result of the intensified agricultural extension programme there should be an increase in native cash crop production. Departmental estimates said that native copra could increase to about 50,000 tons a year, cocoa to 8,000 tons a year and coffee to about 4,300 tons a year. There could also be large increases in production of food for consumption and cash sale. Implementation of the plan would make a major contribution to the advancement of the native people of Papua and New Guinea and the economic development of the Territory.

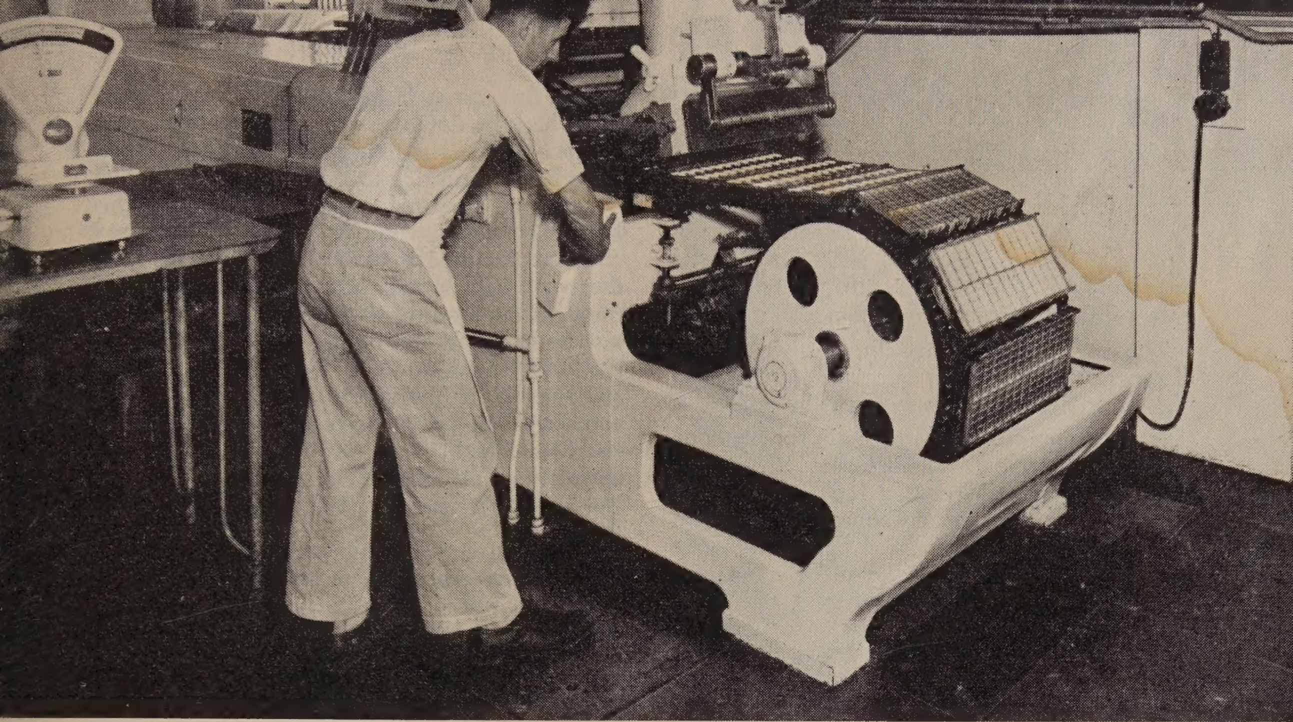


PLATE 1.—*Chocolate tablets being moulded at an Australian factory.*

CACAO PROCESSING—HISTORY AND PRINCIPLES

L. A. BRIDGLAND.

For many years, extensive research into the processes of cacao fermentation, with particular reference to New Guinea conditions, has been under way at Keravat, the Lowlands Agricultural Experiment Station of the Department of Agriculture, Stock and Fisheries. In this article, Mr. Bridgland, former Agronomist-in-Charge of the Station, discusses, in the form of an introduction to the history and principles of cacao processing, the conclusions reached during the research programme. The second article in this issue deals with the practical recommendations of the Department to New Guinea growers. Mr. Bridgland hopes at a later stage to publish in association with his co-worker, Mr. J. B. O'Donohue, the experimental methods and data embodied in these conclusions and recommendations.

HISTORICAL BACKGROUND

THE area covered by the various reaches of the Amazon and Orinoco Rivers, in which wild types of cacao can still be found, is believed to represent the main centre of origin of the crop. It is presumed that the cacao plant became distributed over other parts of tropical America by nomadic tribes, which suggests that these tribes made use of its fruit. In the historical record, it is evident that cocoa beans formed an integral part of the life and economy of the Aztecs, who had been settled in Mexico for nearly 200 years before the conquest of Mexico by Cortes in 1519.

As cocoa beans were used as a medium of exchange, the scale of cultivation must have been quite small. The modern planter no doubt looks back on these times with a feeling

of nostalgia, since a slave could be purchased for 100 beans. Such as it was, a high proportion of the production found its way to court, where the crude but highly-prized beverage prepared from the beans was regarded as a luxury item. According to Jensen (1931), Montezuma was reputed to consume some 50 pitchers a day and he must have gone through life in a perpetual state of theobromine intoxication.

The Aztecs held that the plant was of divine origin and the name *Theobroma cacao* was accordingly conferred on it by Linnaeus.

It is an interesting pastime to speculate on how it first came to be discovered that cocoa beans could be utilized as a food or beverage. Certainly, the taste of unfermented, unroasted beans could scarcely have caused the primitive Indians to look twice at the plant. There is no doubt, however, that the Aztecs and Maya Indians were aware of the necessity for roasting. It is also a fairly safe assumption that some form of crude fermentation was practised. The series of accidental or deliberate treatments from which primitive processing techniques evolved will always remain unknown, but the modern grower owes a considerable debt of gratitude to a few primitive Indians who, having a capacity for observation and experiment, found that by appropriate treatment, cacao beans would yield chocolate flavour.

Chatt (1953) describes the Mexican process as a grinding of roasted nibs between a concave stone and a stone "roller", followed by mixing with corn and spices to form a cake. This could be eaten or beaten with water to the consistency of a thick sauce to which vanilla and other spices were added to form "*chocolatl*". At the time, sugar-cane was unknown in Mexico, and the brew was probably unsweetened. Urquhart (1955) refers to a preparation used by the Maya Indians made by pounding cocoa beans with corn and boiling the mixture with capsicum and water.

These established recipes understandably were not particularly to the liking of the Spanish conquerors who developed "chocolate" as a drink flavoured with sugar, vanilla and cinnamon. Jensen (1931) refers to the first manufacture of "chocolate" cakes by the Spanish physician, Maradon. The addition of sugar to the primitive formulae represents the first major turning point in the history of processing and established the basis of recipes as we know them to-day.

The first cocoa beans to reach Europe were taken back by Columbus, but these were received without much enthusiasm. When Cortes returned to Spain in 1528, he took with him samples of prepared products and from this humble beginning has arisen the highly-organized and complex modern trade in cocoa beans. As the popularity of the chocolate beverage spread through the Courts of Europe, the import of raw beans began and by the middle of the 17th Century, manufacture in Europe had its slow and uncertain beginnings. This represents another milestone in the history of the industry —a decided split in the processing between producing and manufacturing countries developed and this split has solidified with time.

It was not until early in the 19th Century that Van Houten evolved a technique for reducing the fat content of the cocoa bean. This made the beverage more palatable and digestible. Later still came the addition of milk to eating chocolate, the form in which by far the greater proportion of beans is consumed.

Over the centuries, the cacao plant became distributed through the West Indies, San Thome, West Africa and the East Indies to meet the increasing demand brought about by the manufacture of chocolate. The product "boomed" in the latter part of the 19th Century and the early part of the 20th Century. At this stage, manufacturers became discriminating about the quality of cocoa beans. The fundamental lessons learned were that on all counts the flavour of fermented beans was superior to unfermented beans and also that beans of varying genetic origin produced characteristic flavours. The art of blending the different types of beans and processing them to produce desired flavours became a highly-developed skill, about which manufacturers were secretive.

Depreciation of the price paid for unfermented beans led to the practice of "claying" in producing countries. This method was used to deceive manufacturers by reproducing the appearance (externally only) of fermented beans on unfermented beans (Shephard, 1932). "Claying" was widely practised in Trinidad and Venezuela. Beans were given a wash in a suspension of red clay. This imparted uniform and attractive external appearance. It was also believed that claying prevented mould development and preserved aroma. Abuses of

the method, which leave little to the imagination, caused manufacturers to reject or severely downgrade beans which had been "clayed". The process has gradually died out.

The trend away from the use of unfermented beans has continued up to the present time and there is now almost no demand for such beans. Manufacturers soon began to realize that beans could be either well fermented or badly fermented and have become very discriminating on the question of goodness of fermentation. The same beans are capable of producing either good chocolate flavour or almost no chocolate flavour, depending on the grower's processing. Furthermore, objectionable flavours may be acquired during fermentation and drying. It is with this question of getting the best out of cocoa beans that this article is primarily concerned.

In the early days of the trade, the greatest demand was for the so-called "fine" cocoas of the Criollo type. Over the last fifty years, the demand has swung in favour of the "bulk" or Forastero type, although there is still a considerable demand for "fine" cocoas. It is evidently quite fortuitous that the huge plantings in West Africa are of the Forastero type. For the moment, there seems to be a fairly stable equilibrium between demand for the two types but on present indications the relative demand for "fine" cocoas will fall. The processing of the two types shows a good deal of variation but the same principles apply to both.

Over the last 50 years, manufacturers' processing methods have become highly mechanized and fully controlled. The modern chocolate factory is a model of industrial efficiency. Over the same period, the processing carried out by growers has shown no improvement. In fact, it appears to have deteriorated in many cocoa-producing countries. It is not surprising therefore to find that chocolate manufacturers are exerting pressure to hasten research work on the primary processing of the bean. They are themselves undertaking much of this research.

STEPS IN PROCESSING

The processing carried out by growers and manufacturers is complementary. Each should understand the problems facing the other and it will be of value to survey briefly the total processing.

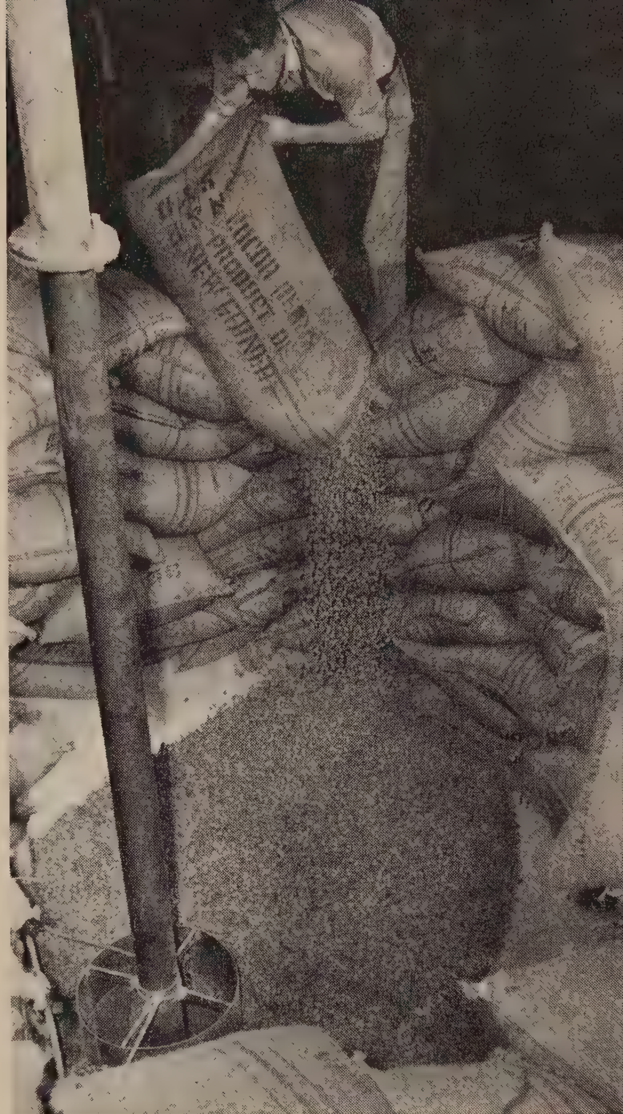


PLATE 2.—*New Guinea cocoa beans are poured into factory hopper.*

Growers' Processing

Ripe pods are removed from the tree. The beans are extracted, fermented, cured/dried and winnowed. Details of these steps are described at a later stage in this article.

Manufacturers' Processing

The dry beans are winnowed to remove rubbish not removed by the grower. They are then roasted in either a "continuous" or "drum" roaster after which the beans are "kibbled".

This consists of shattering the roasted beans. The shell is winnowed off and although saleable for theobromine extraction, is regarded as a waste product by some manufacturers.

The shattered nibs are then ground between steel or stone rollers or in the more modern " liquor mill ". This consists of two pairs of discs, one fixed and one rotating rapidly. The discs are of fluted steel and are water-cooled to prevent overheating and flavour destruction during operation. The " liquor mill " replaces the older " Melangeur " in which sugar and nib were ground together.

Grinding in the liquor mill takes place in two stages. The first stage gives a relatively coarse grind and the second stage a very fine grind. The nibs are reduced to a partially liquid state by the first stage and the second stage yields the so-called " chocolate mass " or " neatwork ".

For the manufacture of cocoa powder, the chocolate mass is usually treated with alkali, this step being known as the " Dutch Process " or " Dutching ". The alkalization neutralizes acidity, causes a darkening in colour and increases the solubility of the cocoa powder. The alkalized chocolate mass then enters " presses " which remove some 60 to 70 per cent. of the cocoa butter and yield " Press Cake ", which forms the basis of all cocoa beverages. The expressed cocoa butter is used in the manufacture of chocolate.

In the manufacture of chocolate, the chocolate mass may or may not be slightly alkalized. Sugar and milk solids (the amount depending on whether the chocolate is to be " milk " or " dark "), some cocoa butter and lecithin are then added before the mixture goes to the " roller grinders ". The lecithin is added to reduce viscosity. Roller grinding takes place in five or six stages. The machine consists of a battery of steel rollers. The whole battery may be vertical or inclined, each successive roller rotating slightly faster than the preceding one. This gives a tearing and rubbing action. Once again, considerable frictional heat is developed and the grinders are water-cooled to avoid overheating and damage to flavour but the mass is allowed to heat sufficiently to bring it to a fluid state.

The chocolate material is allowed to " flake " on the last roller, from which it is scraped. The flaking is achieved by controlling the cocoa butter content of the mixture. As particle size is reduced by grinding, correspondingly more cocoa butter is required to " wet " the particles and maintain the fluid state. Thus flaking at the correct stage is controlled by the amount of cocoa butter added before roller grinding and the fineness of grinding. In addition to reducing the particle size of the cocoa material, the main function of the roller grinders is to grind the sugar (added in the form of icing sugar) to an extremely small particle size.

The ground, sweetened chocolate mass is then " conched " after the addition of more cocoa butter and lecithin to reduce viscosity. The " conch " derives its name from the shell-like appearance of the early designs. There are now various improved versions of the machine. Fundamentally, they consist of a tank, containing the chocolate mixture in a fluid state, in which a relatively large roller runs slowly up and down. The chocolate mixture is " paddled ", so to speak. The tank is, if necessary, heated by a hot-water jacket to maintain the material in the fluid state. The conch has a smoothing rather than a grinding action. There is some argument about what conching achieves. Cocoa butter becomes evenly distributed, oxidation of certain polyphenols may and probably does occur and there is also some volatilization of acetic acid from the chocolate mixture.

Following conching, more cocoa butter may be added to adjust viscosity and the mixture is then stored in large tanks from which it can be piped to any part of the factory.

Before final moulding, the mixture is " tempered ". Cocoa butter may crystallize in any one of three forms usually denoted as " alpha ", " beta " and " gamma ". Of these, only the " beta " form is structurally stable. The crystal structure which develops depends largely on the rate of cooling to below the melting point of the fat. Thus, in tempering the chocolate mixture, the manufacturer controls the rate of cooling so that nuclei of the " beta " form are developed. The structure of the cocoa butter crystal following moulding is thereby predetermined.

Thus the main problems in the manufacture of chocolate are :—

(1) To bring out the best inherent flavour of the beans.

(2) To avoid destruction of flavour or the development of undesirable flavours.

(3) To remove or obscure any defective or unwanted flavours which exist in the dry beans. This is the problem which manufacturers find most objectionable and one which should not arise.

(4) To accomplish all the above at a cost which enables the manufacturers to market their products at a price which will maintain sales at a high and expanding level.

One of the major elements involved in this is economy in the use of the relatively expensive cocoa butter. Thus control of particle size is a major factor. Particle size must be reduced just to the point where the palate cannot detect coarseness. Further reduction unnecessarily increases the cocoa butter consumption.

Manufacturers' methods will not remain constant, but it is unlikely that the type of bean required (in respect of fermentation and drying) will change significantly. Various attempts have been made in manufacturing countries to apply "post-fermentation" or "reconditioning" techniques to beans which have been improperly prepared. Several methods have already been patented and these have been described by Roelofsen (1958). Whether the methods are effective or not seems to be beside the point. Such techniques would be of little use to manufacturers unless all the beans were of uniform defective fermentation. As this is never likely to be the case, it is unlikely that "fermentation" or any part of it will shift to the manufacturing countries.

A shift in the opposite direction is more likely. Producer countries may tend to carry processing to the manufacture of intermediates in chocolate manufacture before exporting. This is already being done in Brazil and to some extent in Ghana. The increasing number of small manufacturers who depend on the purchase of chocolate mass is making this trend possible. From the point of view of the producer countries, this development leads to substantial economies in shipping costs. More important still is the fact that the products of partial manufacture can be stored in the producing country whereas dry beans cannot. This can give the producing country more flexibility in marketing.

There is bound to be a more or less rigid upper limit to this trend, fixed firstly by the capacity of processing equipment in manufacturing countries and secondly by the highly-specialized requirements of many individual manufacturers. Therefore, while the trend to manufacturing in the producing countries may have some appeal for the major producing countries, it has no appeal whatsoever for the minor producers who could find themselves in the position of having nothing to offer but semi-manufactured products on a market where there was little demand for this type of product.

CACAO CURING AND FERMENTATION

The raw, unfermented cacao bean is extremely bitter and astringent, completely lacking in chocolate flavour and generally possesses a most obnoxious taste. By appropriate fermentation, curing and drying, the unpleasant flavours are removed and chocolate flavour is developed. Therefore, it cannot be repeated too often that the whole cocoa industry rests on efficient processing by the grower.

Fermentation may or may not achieve its objectives, depending on whether or not the necessary changes take place within the bean. Manufacturers have learned that beans which are light to chocolate-brown in colour, in which the cotyledons have taken on an open texture and in which the shell separates freely from the cotyledon, are more likely to possess good chocolate flavour and are much less bitter and astringent than beans which do not show these characteristics. Beans in which the required reactions have not gone far enough during fermentation and drying are characterized by varying degrees of white or purple colouration, have a tight cheesy texture and the shell remains firmly attached to the cotyledons or nibs. On the other hand, beans in which the necessary reactions have gone too far are usually very dark in colour of both skin and cotyledons and the colour is "dull" rather than bright. This "over-fermentation" is associated with a variety of foreign flavours of the "earthy-foetid-foul" type and there is a considerable weakening of chocolate flavour.

It is evident therefore that during successful fermentation major changes take place within the beans and it has become a matter of great importance to know what these changes are and what conditions are necessary for them to take place.

Early Studies of the Cocoa Bean

The first logical step was to conduct chemical analysis of both unfermented and well-fermented beans as it was thought that the comparison of the two analyses would throw light on the changes which take place. At the same time a chemical scrutiny was made of the pulp, since this was the fermenting medium. It was believed that part at least of the flavour of the fermented beans could be due to the production in the pulp of substances which entered the bean to produce the desired flavours.

This type of analysis was carried on for many years in the early part of this century and much useful information was obtained, but the investigations did not throw much light on what constituted the essential reactions. These early studies covered, *inter alia,* alteration which accompanied fermentation in the content of fats, carbohydrates, proteins, mineral constituents, theobromine and the broad group of pigments and tannins. It was found that almost every constituent showed some alteration during fermentation and it gradually emerged that it was the changes occurring in the polyphenolic fraction, which were somehow or other connected with the development of chocolate flavour.

The fresh cacao bean contains about a dozen different polyphenolic substances. Most of these have recently been identified with the help of chromatographic techniques—techniques which have given renewed impetus to research work on the chemistry of the cacao bean. There is a great number of names attached to these chemical investigations but without minimizing the value of the results obtained by the early investigations it is the recent work which is of greatest interest. In particular, the studies of Forsyth in Trinidad, Rohan in Ghana and Roelofsen and Giesberger in Java are highly relevant. It is only within the last few years that results capable of modifying field practice have been obtained.

Paralleling the chemical investigations, various experimenters have approached fermentation on the commercial scale on a "trial and error" basis. Conditions of fermentation have been varied in many ways and the effects judged by the altered pattern of fermentation and by the acceptability of the finished product. Until fairly recently, such work was largely unsupported by parallel chemical investigations, mainly because of lack of suitable techniques. Consequently the results obtained by different workers were contradictory in the extreme. However, much valuable information has been accumulated and as the chemistry of the processes becomes clearer the conflicting results obtained in the field will probably become reconciled. The effects of varying field conditions have been studied in recent years by Howat and Powell, Rohan, Roelofsen and Giesberger and in New Guinea.

Microbiological aspects of fermentation have generally been given insufficient attention in New Guinea and elsewhere. Knowledge of the subject up to 1937 was summarized by Knapp (1937). Since then, the major contributions on this subject have come from Rombouts and Forsyth working in Trinidad and further information has been obtained by Roelofsen and Giesberger working in Java.

The final test of theoretical knowledge is to reproduce the conditions thought to be necessary on a laboratory scale and compare results with those obtained using the best field methods. If the principles have been correctly understood and correctly applied, there seems to be no reason why equivalence cannot be obtained. If such laboratory techniques existed, then work on relating the fundamental principles to actual field methods would be greatly assisted. Over the last 50 years, various workers have attempted to evolve satisfactory small-scale methods, not so much for the reason just stated but mainly as a means of testing the flavour of individual clones. Until a few years ago, these attempts suffered from a lack of knowledge of the basic principles. None of the early methods produced beans with a normal chocolate flavour. For example, the method developed by the General Foods Corporation in 1948 produced chocolate which has been described as "distinctly unlike normal chocolate". This was followed by the methods of MacLean (1950) and de Witt (1951). In 1954, Wadsworth and Howat produced a method which is claimed to produce a normal chocolate flavour. This work is of noteworthy importance since an attempt was made to elucidate principles from variations in the method. Since then, the method of Quesnel (1957) has been published and this method is the only one which attempts to utilize knowledge of the chemical reactions known to take place during successful fermentation. It can

perhaps be anticipated that completely satisfactory methods will be evolved within the next few years by refinement and perhaps synthesis of existing methods. It should then be possible to vary the different factors affecting fermentation under controlled conditions and this should lead to a stronger linkage between theory and practice.

Chemical Changes and Flavour Development

Research workers have long suspected that the chemical changes associated with the development of chocolate flavour are mainly concerned with the polyphenolic and "tannin" fraction. Workers who have taken part in recent chemical investigations (Rohan, 1951 ; Forsyth, 1957 and Roelofsen, 1958) classify these compounds into two major groupings :—

(*a*) Phenolic glycosides—in which the polyphenols exist in combinations with sugar molecules. The most important compounds here are the anthocyanins ; and

(*b*) Non-glycosidic polyphenols—some of which occur as such to begin with and some of which are produced as a result of hydrolysis of the glycosides during fermentation. The principal compounds here are catechins and leucocyanidins.

Forsyth (1957), whose work is a milestone in cacao research, has shown that the essential chemical changes associated with cacao fermentation take place in two distinct phases which he terms "The Anaerobic Hydrolytic Phase" and the "Oxidative Condensation Phase".

1. *Anaerobic Hydrolytic Phase.*

This involves the first series of chemical changes which takes place within the bean. In these reactions, the sugar molecules are split off the glycosides [Group (*a*)] by the action of a glycosidase enzyme. This process is anaerobic and Forsyth has produced evidence showing that the reaction is inhibited if preceded by oxidative changes. Chocolate flavour precursors are formed as a result of these reactions. If for any reason they fail to take place, chocolate flavour will not be developed.

Other complex chemical changes accompany the hydrolysis of the anthocyanins. Forsyth has shown that these are interactions between the phenols and the proteins and that these reactions have a marked influence on the solubility and flavour properties of the compounds concerned. The reactions are not well understood.

2. *The Oxidative Condensation Phase.*

According to Forsyth (1957), the oxidative reactions primarily concern the non-glycosidic polyphenols and polyphenol aglycones [Group (*b*)] liberated by hydrolysis of the anthocyanins. Oxidative changes take place through the agency of another enzyme—polyphenol oxidase. The reactions increase the insolubility of the polyphenols and this mitigates their bitter/astringent taste and also removes the nauseating taste of roasted fresh protein. In this way, the oxidative changes exert a considerable effect on the overall flavour of dried beans.

Additional Results Relating to the Development of Chocolate Flavour

The changes noted above and the order in which they take place now appear to be firmly established by the work of Forsyth and coworkers. There are, however, certain results which suggest that there are other important reactions which are not understood fully.

It is generally agreed that reactions associated with the anaerobic phase are of fundamental importance but there is some disagreement regarding the optimum conditions and the rates of the reactions. These questions are discussed later. As regards the oxidative phase, the chemists generally believe that the associated reactions play no part or only a relatively insignificant part in the development of chocolate flavour as such and that the influence of the oxidative reactions is, in a sense, negative. This is in direct conflict with the basis of quality assessment used by manufacturers. While buying beans primarily for their flavour, manufacturers base their method of assessment very largely on the degree of "browning", which is merely a rough measure of the level of oxidation. This basis gives no assurance of satisfactory completion of the anaerobic hydrolytic phase which results in the formation of the chocolate flavour precursors. If oxidative changes are not preceded by destruction of the anthocyanins by the glycosidase enzyme, it is possible to obtain brown, open-textured beans completely lacking chocolate flavour. This has been accomplished experimentally at Keravat and by Smith (1958) in Rabaul.

The results obtained at Keravat suggest that the oxidative reactions, when preceded by normal anthocyanin destruction, have a direct influence on chocolate flavour development. In a series of trials, beans were withdrawn from a fermenting mass at various intervals following bean death. Portion of these samples was pierced with a dissecting needle and the remainder was left unpierced. All were then sun-dried. The pierced beans all became plump and open-textured, while the unpierced beans remained flat and wrinkled and were cheesy-textured and purple or white in varying degree. Beans which were pierced eight hours after bean death developed strong chocolate flavour and the cotyledons had a distinct purple cast. Unpierced beans withdrawn at this stage developed no chocolate flavour. They were cheesy in texture and showed very little browning.

Beans which were pierced 24 hours after bean death developed very strong chocolate flavour and the cotyledons, although open-textured, had a slight purplish or whitish cast. Unpierced beans at this stage developed extremely weak chocolate flavour. Piercing at later stages of fermentation led to a reduction in chocolate flavour whereas the chocolate flavour of unpierced beans improved. Piercing at later stages also led to complete removal of purple pigmentation.

The chocolate flavour developed by beans pierced 24 hours after bean death was considerably stronger than is normally encountered in commercial beans in New Guinea. This indicates that the hydrolysis of anthocyanins was complete or virtually complete at this stage. Unpierced beans, taken at the same time, which developed extremely weak chocolate flavour, were also somewhat bitter and astringent, but the extent of anthocyanin hydrolysis must be presumed to have been the same or else oxidative changes did not inhibit the activity of the glycosidase enzyme.

There are only two ways of regarding the absence of chocolate flavour in the unpierced beans withdrawn 24 hours after bean death. Either the flavour is there but cannot be tasted owing to the masking effect of bitterness, or it is not developed in a form which gives the characteristic taste without the added changes brought about by oxidation.

Further investigation is required to determine which of these two explanations is correct. In a further series of trials at Keravat, beans were fermented under completely anaerobic conditions. The beans were then divided into three lots. the first lot was pierced and sun-dried. The second lot was unpierced and sun-dried. The third lot was dried in an atmosphere of CO_2. The beans which were pierced and sun-dried developed strong chocolate flavour. The beans which were not pierced and sun-dried developed mild chocolate flavour. The chocolate flavour could not be detected in beans dried in an atmosphere of CO_2. They tasted extremely bitter and astringent. This confirmed the results obtained by Wadsworth and Howat (1954).

The results of these trials, however, do not meet the anticipated objection that the chocolate flavour may be completely masked by bitter-

PLATE 3.—*Fermentation trials at Keravat. Note use of thermometers in fermenting mass.*

ness or astringency. This is a question which cannot be settled one way or the other until the compounds actually responsible for chocolate flavour have been isolated and identified. The "tasting test" is entirely subjective. The expert panel of tasters used in the above trials were of the opinion that if chocolate flavour were present in the beans dried in an atmosphere of CO_2, it could have been detected. This was also the writer's opinion. It seems unlikely that if the chocolate flavour were fully developed it could not be tasted at all. With beans fermented under anaerobic conditions and dried in CO_2, prolonged grinding was successful in reducing the level of bitterness, but chocolate flavour was still not revealed. It seems very probable, therefore, that the precursor formed on hydrolysis of the anthocyanins (P_1) requires oxidation to form precursor (P_2) which on roasting will yield chocolate flavour as such.

If a certain level of oxidation is essential, it is equally clear that too much oxidation is very harmful. It is a well-established fact that the longer the fermentation the browner the beans become when dry. Bridgland's (1959) results indicate that the extent to which beans become brown during drying is a linear function of the Time/Temperature product during fermentation. This does not necessarily imply continuous oxygen uptake during fermentation, but it certainly indicates that the susceptibility of the bean to oxidative changes (whether these occur during fermentation, drying or both) is a function of the Time/Temperature product. In a rough way, the piercing and drying of beans withdrawn at regular intervals during fermentation gives a regular increment in the extent of oxidative reactions. The piercing and drying of beans withdrawn more than 24 hours after bean death leads to an increasing overdosage of oxygen and to progressively weakened chocolate flavour. If such an overdose can destroy chocolate flavour, the susceptiblity to oxidative reactions of the compounds concerned with actual chocolate flavour must be accepted.

It is now worth recalling the finding of Wadsworth and Howat (1954) that beans maintained in an atmosphere of CO_2 during either fermentation or drying develop no chocolate flavour. This result is explicable in terms of an inhibition of essential oxidative changes if the oxidative reactions are restored to their rightful place in the scheme of things. Furthermore, the temperature optimum claimed by these workers can be viewed in a new light. This is discussed later.

At all events, even if the effect of the oxidative changes is to "unmask" chocolate flavour rather than to lead to its development, the above results indicate that these reactions are quite as important as those accompanying the anaerobic phase. It would give manufacturers no satisfaction to know that the flavour precursors are present if they cannot be tasted. If the oxidative changes do in fact make a positive and direct contribution to chocolate flavour, when preceded by the hydrolysis of the anthocyanins, then manufacturers' methods of visual assessment do not appear to be so inaccurately based.

Objects of the "Fermentation" Phase

(As distinct from the "Drying" phase.)

At this point, it has to be decided whether the reactions associated with the anaerobic hydrolytic phase constitute the only object of the fermentation phase; that is, the phase in the sweat boxes. Forsyth and Rombouts (1951) claim that this is substantially the case. At once a great discrepancy between the theoretical minimum duration of fermentation and the practical optimum becomes evident. It has been shown (Bridgland, 1959) that under reasonable to good conditions of temperature and acidity during fermentation fundamental precursor development (P_1) is complete, or very nearly complete, in beans which are dried 24 hours after bean death has occurred. This is fully supported by Rohan's (1957) chemical investigations in Ghana where it was shown that in beans withdrawn from the surface layers of fermenting heaps and dried the anthocyanin concentration had fallen to 10 per cent. of its original value after 48 hours' fermentation, i.e., 24 hours after bean death. Furthermore, Quesnel (1957), using his laboratory technique, found that chocolate flavour was well developed after 24 hours only. The standard plantation practice in Java is to ferment for two and a half to three days, giving less than 48 hours' fermentation following bean death.

Therefore, provided satisfactory conditions are obtained, if completion of the anthocyanin hydrolysis is the only object of the fermentation phase, then the duration of the whole process could be reduced to two and a half days. This

can be, and in fact is, done in Java and Ceylon, but such fermentation must be balanced by very long and carefully controlled drying.

The interesting point is that most countries find it a distinct advantage not to follow this practice of short fermentation. Forsyth (1957) prefers a six-day fermentation for Trinidad. Although they have developed a method of fermentation which rapidly brings about anthocyanin hydrolysis, Rohan and Allison (1958) prefer a six-day fermentation with their method. Where optimum conditions for anthocyanin hydrolysis are quickly reached by methods evolved at Keravat, the results of six-day fermentation are far superior to the results of shorter fermentation. Roelofsen (1958) also states that fermentation for four and a half days, in Java, produces beans with stronger flavour than those fermented for three days or less.

The reason for this divergence between the theoretical minimum and the practical optimum has not been properly explained. Forsyth (1957) explains it on the basis of variable conditions in the mass of beans and the necessity for obtaining uniformity by mixing. This explanation is inadequate.

There is good reason to believe that prolongation of fermentation beyond three days is almost entirely for the benefit of the oxidative condensation phase. This involves the proposition that the objects of fermentation are to complete the reactions associated with the anaerobic phase and to initiate and partially complete reactions associated with the oxidative phase. The rationale of this is that it is cheaper to obtain necessary oxidative changes in the inexpensive sweat-boxes than in very costly drying equipment. The increased extent of oxygen uptake and the increased susceptibility of the bean to oxidative changes as the Time/Temperature product expands, greatly simplify the problem of "drying" and reduce its costs.

If partial completion of oxidative reactions should form a principal object of fermentation, then the conditions most favourable to these reactions is a matter which has been largely overlooked. That oxidative changes can take place to a considerable extent during fermentation is fully supported by observation. That they actually do so until the very end of fermentation is disputed by Forsyth and Rombouts (1951) who claim that it is necessary to maintain virtually anaerobic conditions within the bean for four or five days and that "browning" of the cotyledons does not occur during fermentation until the sixth day. Experience in New Guinea conflicts with this view and indicates that considerable oxygen uptake after the third day of fermentation is not only possible, but very desirable. The case for this proposition is expanded at later points in this article (Ref. p. 61.—"Conditions Required for the Oxidative Condensation Phase").

Normal Fermentation of Pulp

The chemical changes taking place within the bean are entirely dependent on changes occurring in the pulp as a direct or indirect result of the activity of micro-organisms. Changes in the pulp usually follow a sequence which appears to be similar under all conditions. There are, however, exceptions to this and the intensity and duration of different actions taking place within the pulp evidently vary a great deal. What is "normal" in Trinidad or Ghana is not "normal" in New Guinea.

Fresh beans become inoculated with many organisms during "breaking" and transport but after a few hours of fermentation the yeasts predominate (Rombouts, 1952). The pulp sugars are metabolized by the yeasts with the production of carbon dioxide and alcohol. At the same time the yeasts macerate the pulp cells which collapse and conditions become more anaerobic. These conditions favour the action of the lactic acid bacteria, the role of which appears to vary from place to place. They are relatively unimportant in Trinidad but seem to be more important in Java. Roelofsen and Giesberger (1958) state that the main product of their activity under sweat-box conditions is acetic acid.

Under New Guinea conditions (Bridgland, 1959), extractions of titrable acid from the pulp show that there is a sharp fall in the overall acidity for the first 36 hours of fermentation. This is attributed to breakdown of citric acid, occurring naturally within fresh pulp. There is a corresponding rise in pH of the pulp over this period but the pH of the cotyledon shows very little change.

With greater maceration of the pulp, conditions become more aerobic favouring the growth of the acetic acid bacteria which convert the alcohol produced by the yeasts into acetic

acid. There is some rise in the temperature of the mass of beans during the period of maximum yeast activity but striking rises in temperature accompany the acetic phase. The rate of temperature rise varies a great deal from place to place. It is a good deal slower in New Guinea than in West Africa. Even on the same estate there are considerable seasonal fluctuations, but normally the temperature rises to about 45 degrees C. within three days and may rise to 50 to 51 degrees C. a day or so later.

In Trinidad, micro-organisms reach their greatest concentration after two days of fermentation (Rombouts, 1952) after which there is a spectacular fall. After the third day, the number of organisms present is relatively very small but temperatures of 45 to 50 degrees C. are maintained until fermentation ends after six to eight days.

following the addition of dextrose on the third day of fermentation.

After the first 36 hours, there is a considerable production of acetic acid. The effects and significance of this are discussed below. Under New Guinea conditions the level of titrable acid normally shows a fairly steady rise to the end of fermentation (Bridgland and Friend, 1957). The pulp, however, usually buffers out at about 4.5. Cotyledon pH falls from about 6.2 initially to about 4.0 or 4.5 by the fourth day and remains fairly constant for the remainder of fermentation. Should the level of acidity be low, the cotyledon pH may show a considerable rise towards the end of fermentation, but this occurs only when special steps are taken during fermentation.

At the beginning of fermentation, the beans when cut show a bright purple or violet pig-

PLATE 4.—*Trial lots of beans are dried at Keravat.*

The more anaerobic yeasts die out quickly during a normal fermentation, but Roelofsen and Giesberger (1958) have shown that certain aerophilic yeasts are present in small concentration side by side with the acetic acid bacteria, following the lactic acid bacteria. A significant rise is acidity has been obtained at Keravat

mentation in Forastero or hybrid beans, but no pigmentation in Criollo beans. There is no visible free moisture within the beans and the cotyledons are tightly bound together. After 30 to 40 hours' fermentation (i.e., after bean death) the cotyledons show some slight separation and all interstices within the bean are filled

with a fluid which is inky in pigmented beans and clear in non-pigmented beans. With further fermentation the beans take on a bleached look and the cotyledons show additional slight separation fragmenting easily between the fingers and separating easily from the testa.

The free liquid within the bean becomes quite "muddy" by the fourth day of fermentation and a "brown ring" appears in the cotyledon tissue adjacent to the testa on the fourth or fifth day. This browning gradually moves inward, but is usually variable in extent at the end of fermentation, depending on the level of aeration.

The visible internal changes noted above are accompanied by striking changes in the external appearance of the beans. The pulp and the testa are both white initially. The pulp collapses during the period of yeast dominance and becomes off-white in colour. With the onset of the acetic phase following improved aeration, the pulp becomes light fawn and this changes to light brown and then to dark brown by the end of fermentation. The more acid the conditions, the lighter the colour. The progressive browning of the pulp is generally attributed to the extrusion from the cotyledons of tannins which are oxidized to become brown.

CONDITIONS REQUIRED FOR ANAEROBIC HYDROLYTIC PHASE

1. *Bean Death*

The pigmented polyphenolic compounds are not uniformly distributed throughout cotyledon tissue in fresh, unfermented beans. They are localized within special groups of storage cells. The glycosidase enzyme is located in cells other than the pigment cells (Forsyth, 1957). It is only when the beans are killed that the polyphenols become evenly distributed throughout cotyledon tissue. Only then can the enzyme attack the anthocyanins.

The progress of fermentation can be uniform only if there is a clearly-defined starting point for the essential reactions taking place within the bean. This point is established when the beans die. It is for this reason that the question of the cause of bean death becomes important. This is considered later.

2. *Absence of Oxygen*

As noted above, Forsyth has shown that the activity of the glycosidase enzyme is inhibited by the intermediates of oxidase activity. Therefore conditions within the bean must remain anaerobic until the anthocyanin hydrolysis is completed. It is evident from the foregoing that such anaerobic conditions should be maintained for the first three days of fermentation. This period coincides with the period of maximum microbial activity (Rombouts, 1952) and it has already been pointed out by various workers that even under conditions of good aeration in the mass, the extent of oxygen penetration to the cotyledons is likely to be negligible during this phase. It is interesting to note that the first visible signs of appreciable oxygen uptake occur on the fourth day even under conditions of good aeration. This occurs after the dramatic decline in the numbers of active micro-organisms during the third day as demonstrated by Rombouts (1952).

It may be concluded, therefore, that, as a general rule, no special steps are required to maintain anaerobic conditions within the bean over the vital period.

3. *pH*

It has been shown by Forsyth and Quesnel (1957) that the glycosidase enzyme is most active in destroying the pigments of cacao cotyledon tissue at a pH between 3.8 and 4.5. The difference in rate of activity within this range is slight. At pH below 3.5 the rate of activity falls off very rapidly. Above pH 4.5, the rate of activity falls off more gently but at pH 6.0 the rate is about two-thirds that at pH 4.0.

4. *Temperature*

Forsyth (1953) has shown that in unfermented, dehydrated bean powder there is considerable non-enzymic destruction of the anthocyanins above 55 degrees C. but at the temperatures normally encountered in commercial fermentations (45 to 50 degrees C.) the destruction which occurs is caused by the activity of the glycosidase enzyme to the extent of 75 per cent. Further, the optimum temperature for the enzymic hydrolysis is sharply defined at 44.5 degrees C. The rate of conversion is very much less at a temperature of 40 degrees C. With live beans, it was concluded that "provided the temperature exceeds 44 degrees C. for about three days, practically complete destruction of the pigment should occur".

Temperature/pH interactions are probably deserving of further study. It seems likely that where optimum pH and temperature are obtained

together, the reaction will be completed in considerably less than three days. Experience at Keravat suggests that temperature is the more important determinant. This agrees with results obtained by Rohan (1957) where it was shown that beans withdrawn from the surface of fermenting heaps before there was any significant reduction in pH, but which had reached a temperature of 45 degrees C., had lost some 90 per cent. of their original anthocyanin content by the time the beans were dry.

To return to a consideration of the optimum temperature pattern during fermentation, there is some disagreement between the results of Wadsworth and Howat (1954) and Forsyth (1953). Wadsworth and Howat state that a temperature of 50 degrees C. is essential to the full development of chocolate flavour. It is suggested that the two conflicting temperature optima, 45 degrees C. on the one hand and 50 degrees C. on the other, may actually refer to the temperature optima for two different phases. Perhaps the temperature should reach 45 degrees C. for the anaerobic phase and 50 degrees C. for the initiation and partial completion of the oxidative phase. Results obtained at Keravat on a commercial scale over the past five years indicate that chocolate flavour is appreciably stronger from fermentations at 50 degrees C. than at 45 degrees C. In further support of Wadsworth and Howat, fermentation temperatures of 40 to 45 degrees C. have usually been associated with strong side-flavours such as liquorice, raisin or caramel.

The results of piercing trials (Bridgland, 1959) at Keravat which indicated very rapid completion of the anaerobic phase, suggest that beans need to be held near the optimum of 45 degrees C. for this reaction for only about one day. Further experience indicates that for the remainder of fermentation the temperature optimum is about 50 degrees C.

CONDITIONS REQUIRED FOR OXIDATIVE CONDENSATION PHASE

Oxidative changes depend on the activity of the enzyme polyphenol oxidase. The factors which are capable of modifying the rate of oxidase activity are the concentration of the enzyme and the conditions under which it has to operate. There is no evidence to suggest that enzyme concentration ever becomes a limiting factor. Provided other requirements are fulfilled, beans can invariably be made to go brown.

Two sets of conditions are required for oxidase activity, namely those occurring in the sweat-box and those occurring during drying. The latter are more conveniently dealt with under the heading "Curing/Drying". As far as the fermentation phase is concerned, the factors which immediately suggest themselves as being of potential importance are the availability of oxygen to the enzyme and the temperature, moisture, pH/acidity complex.

At the end of the anaerobic hydrolytic phase, cotyledon pH should ideally be somewhere between 4.5 and 5.0. Findings on the optimum pH for polyphenol oxidase are contradictory. De Witt (1951) claims that it is strongly defined at 5.0, but Roelofsen (1958) states that it is about 7.0; further, that as pH falls, so does the rate of enzyme action; that activity is still present, but at a very reduced rate at pH 4; and that there is no activity at pH 3. In practice a cotyledon pH above 5.0 by the end of fermentation will almost invariably be associated with putrefaction.

Very little information is available on the temperature optimum for the action of polyphenol oxidase. Quesnel (1957) has stated that there is no marked temperature optimum within the range 30 to 40 degrees C., but has informed the writer in private correspondence subsequently that above 40 degrees C. the activity is about 25 per cent. higher than 30 degrees C. Certain results regarding the heat stability of the enzyme are available but do not appear to be relevant to the optimum. The question of temperature in relation to oxidase activity is still open and further work is necessary.

Moisture content of the cotyledon tissue cannot become limiting during the fermentation phase and is considered in the section on drying.

The weight of evidence indicates that the rate and extent of oxidative changes occurring during fermentation are limited by the rate of oxygen penetration of the testa. Roelofsen (1958) suggests that the rate of oxygen uptake becomes greater as fermentation is prolonged due to increased permeability of the testa. He claims to have demonstrated this by pressing air into beans while they were steeped in water

and suggests that the increased permeability is due to the action of pectinase produced by yeasts, spore-forming bacteria and other bacteria such as *Aerobacter.* There is no doubt that the testa is an imposing barrier. Forsyth (1952) found that when cotyledons were ground all polyphenols were oxidized so rapidly and extensively that they became insoluble within an hour.

Under the saturated conditions prevailing in the sweat-box, any oxygen penetration of the bean must occur in the dissolved state. Oxygen penetration is therefore a function of aeration of the mass in the first instance. The only oxygen available for penetration of the bean is that which is not immediately metabolized by micro-organisms. As noted above, the activity of micro-organisms shows a dramatic decline from the second to the third day of fermentation. Oxygen penetration of the bean may be aided by moisture uptake by the bean during fermentation. Beans do show an increase in moisture content during fermentation (Howat, 1957), but it is not known whether this is caused by the direct uptake of moisture. As pointed out by Forsyth and Rombouts (1951), all interstices within the bean are filled with juice containing polyphenols, particularly L—epicatechin, in solution. As oxygen enters the bean, this is precipitated. Completion of this precipitation is therefore an essential condition for oxidation of polyphenols occurring within the cotyledons. Because of these barriers, Forsyth concluded that browning of the cotyledons cannot occur to any significant extent during fermentation and that what is commonly regarded as "browning" is in fact a "bleaching" only. This is not necessarily so.

Browning can and does occur during fermentation. In trials conducted at Keravat, fresh beans were taken and excess pulp rubbed off (Bridgland and O'Donohue, unpublished). Several groups of 10 beans were then placed in small, airtight, thin plastic bags and just covered with one per cent. acetic acid. These were then sealed and buried in a normal fermenting mass as soon as the mass reached a temperature of 45 degrees C. and were maintained at this temperature for four days. At the end of this period, the cotyledons were certainly bleached but showed no evidence of browning whatsoever. Beans from the mass at the same time showed a high degree of browning. In fact some beans were completely brown. The mass was fermented in a way which ensured adequate air penetration.

Quite apart from the optimum conditions required for the oxidase, conditions of temperature and acidity should be considered in relation to possible effects on oxygen penetration of the bean. In trials covering only the normal range of temperatures occurring during fermentation (i.e., not exceeding 50 degrees C.) Bridgland (1959) has shown that the extent of browning in dry beans is a linear function of the Time/Temperature product. This immediately indicates that temperature is a major factor and, in view of the foregoing, this effect is more likely to be caused by increased oxygen uptake at higher temperatures than by an effect on the rate of activity of polyphenol oxidase. Beans fermented at 50 degrees C. showed a much higher degree of browning than beans fermented at 45 degrees C. Above the normal temperature limits, results were not the same, but as very much higher temperatures are associated with lower acidity and perhaps abnormal moisture relations between pulp and cotyledon it is impossible to separate out the effects (Bridgland 1959—see 1,138 series). However, it did appear that the level of acidity had no effect on oxygen penetration of the testa.

Although the effect of time—generally the longer the fermentation the greater the oxygen uptake and the browner the dry beans—is well known, the maximum duration of fermentation is fixed by the onset of putrefactive changes. Fermentation must be stopped before this occurs and duration of fermentation is not a factor which can be varied independently of other factors.

There is one other important condition for the oxidative condensation phase. This is the satisfactory completion of the anaerobic hydrolytic phase. Whereas the degree of browning is a linear function of the Time/Temperature product when the testa is unbroken, if beans are pierced and dried at regular intervals during fermentation the degree of browning no longer shows this linear relationship. The rate of browning shows a sharp increase after the 700th-900th "degree hour". This roughly coincides with the period at which chocolate flavour precursors are fully developed—that is, with completion of the anaerobic hydrolytic phase of fermentation.

This suggests that the bean is rendered more susceptible to oxidative changes as the anthocyanins are destroyed and, further, that the presence of unhydrolysed anthocyanin in a bean imparts a resistance to the essential oxidative changes. Rohan (1957) has shown that "pale-purple" beans (i.e., beans which have failed to become open-textured and brown) frequently contain only 10 per cent. of the initial anthocyanin concentration. Nevertheless, they have failed to become brown and open-textured because of insufficient oxygen uptake. This, together with the results of piercing trials, is the basis of the statement (Bridgland, 1959) that the "under-fermented bean" (as distinct from the unfermented bean) is basically an "under-oxidized" bean.

In trials at Keravat (Bridgland and O'Donohue, unpublished), beans pre-killed by freezing were placed in small polythene envelopes containing one per cent. acetic acid and buried in a normal fermenting mass for varying periods. This was done in such a way that all samples were withdrawn from drying at the same time. Results on cutting showed that the appearance of purple pigment and under-fermented beans decreased markedly as the duration of fermentation increased. Fermentation was quite anaerobic, but all beans were equally exposed to oxidative changes during drying. Forsyth (1957) has shown that the purple anthocyanins are capable of being attacked by polyphenol oxidase, but this reaction does not result in the formation of chocolate flavour precursors. It is reasonable, therefore, to conclude that anthocyanin hydrolysis is associated with a loss of resistance to oxygen uptake by the bean. If this were not so, all beans should have become equally brown. In practice, incomplete destruction of the anthocyanins could be caused by a prolonged deferment of bean death or unsatisfactory conditions for the activity of the glycosidase enzyme involving temperature pH or premature oxygen uptake.

A direct chemical inhibition of oxidative changes by anthocyanin appears to be unlikely but there are physical changes associated with anthocyanin hydrolysis which could affect the uptake of oxygen. In contradiction to Quesnel (1957) who states that there is a slight unfolding of the cotyledons prior to bean death, observation under local conditions indicates that there is no change in the texture of the cotyledons until after bean death has occurred. As the anthocyanin hydrolysis proceeds, the cotyledons show quite definite signs of progressive shrinkage. This shrinkage is accompanied by a filling up of all interstices with liquid. Whether there is ingress of moisture from outside the bean is for the moment beside the point. Skinned fresh beans, containing no visible free moisture when buried in a normal fermenting mass in small polythene bags, show considerable extrusion of free moisture within 24 hours of bean death (Bridgland, 1959). This can have derived only as a result of extrusion from cotyledon tissue and is accompanied by corresponding shrinkage. It may be that, if destruction of the anthocyanin is limited, shrinkage is also limited and this may interfere with oxygen uptake later on. It is also possible that moisture uptake by the bean is affected by the extent of anthocyanin destruction. Howat's (1957) figures certainly show that the greatest apparent increase in moisture content occurs between 24 and 48 hours of fermentation, coinciding with the period of maximum anthocyanin destruction.

To summarize, experience at Keravat indicates that the conditions required for the oxidative phase consist of satisfactory completion of the anaerobic hydrolytic phase, adequate aeration of the mass and a temperature of 50 degrees C. Other factors not yet understood may also be important.

EXAMINATION OF VITAL FACTORS DURING FERMENTATION PHASE

Although there may be some haziness about some of the precise conditions required for successful curing of cacao, we at least now have a series of definite objectives. The pattern of fermentation of the pulp shows a good deal of variation and is bound to have a profound influence on the conditions to which the contents of the bean are subjected. Thus the interplay of factors governing the conditions of known or supposed importance to the full development of chocolate flavour deserves full consideration.

1. *Viable Period of Beans*

In all methods of fermentation there is a period at the beginning during which the beans are fully viable. Loss of viability is not uniform throughout the mass in ordinary box fermentation. As practised in New Guinea, there is a

high loss of viability in the surface layer after 24 hours, but not in the centre of the mass. Most beans, however, are dead after 36 hours and no viability whatever remains after 48 hours. Rohan (1958) has obtained similar results in heap fermentations in Ghana.

Attention has been drawn to the possible importance of the preliminary period of viability by Wadsworth and Howat (1954). These workers claim that a viable period of 84 hours is necessary to the full development of chocolate flavour and that no chocolate flavour is produced if this phase in eliminated. Dr. Howat has informed the writer in private correspondence, however, that there is very little flavour lost by reducing the period of viability to 48 hours. The interpretation of these results is difficult but it is presumed that the initiation of the germination process results in a mobilization of essential enzymes.

This claim has been the subject of a great deal of contention and some evidence to the contrary has been produced by Quesnel (1957). Early results obtained at Keravat fully supported the view that a viable period of 48 hours does much to assist the development of chocolate flavour and that chocolate flavour is extremely weak if the viable period is eliminated (Bridgland, 1959). In practice, it has so far been impossible to maintain viability for 84 hours without actually initiating germination and this of course is most undesirable.

In further trials at Keravat (Bridgland and O'Donohue, unpublished), results have been irregular and impossible to interpret. Methods of fermentation which allow a period of viability of only 30 hours have yielded beans with a very strong chocolate flavour. Much more work is required before the importance of the period of viability can be properly assessed.

Assuming that a period of viability is necessary, it is not known whether it affects the actual flavour potential of the bean or merely the rate of reactions leading to the development of chocolate flavour. If it should be the latter, it is possible that the same effects could be produced by altering the duration of fermentation or some other factor. Further work is required to clarify the position, but in the meantime, in attempting to evolve an improved technique for New Guinea, it has been found easier to obtain other essential conditions if the period of viability is of about 30 hours' duration.

Given optimum conditions, this results in the development of strong chocolate flavour.

Control of the period of viability at Keravat has been achieved through the use of what we have termed a "resting phase" prior to bean death. Beans are placed in a draining box for 14 to 16 hours after "breaking" and sweatings are allowed to drain away. The beans are then spread out on a shaded, wooden floor at the rate of one cubic foot of beans to 10 square feet of floor-space. With periodic stirring, full viability can be maintained until the beans do in fact begin to germinate. While the holding of beans in a viable state presents no particular problem, there are other important auxiliary effects which exert a powerful influence on the progress of fermentation. The condition of the pulp unfortunately does not remain static when the period of viability is prolonged. These effects are discussed later.

2. *Time and Manner of Bean Death*

Argument on the cause of bean death has been going on for the last 50 years and still continues. Bean death has been variously attributed to the simple thermal effect of high temperature and to poisoning by alcohol, acetic acid and carbon dioxide.

From the weight of evidence accumulated overseas and from experiments conducted on this station (Bridgland, 1959), there appears to be little doubt that the primary cause of bean death is acetic acid. Increased temperature must increase the lethal effect of acetic acid, but there is little evidence available on this point.

In trials at Keravat, beans have been subjected to the normal sweat-box temperature pattern over the critical period both in the presence and absence of normal acetic acid development. Loss of viability was deferred by approximately 10 hours in the absence of acetic acid. Furthermore, when more or less acetic acid was produced by varying the pattern of fermentation, there was a direct relationship between the extent of acid development and the rate of loss of viability.

No one has ever questioned the fact that beans can be killed thermally. But because sufficiently high temperature in a mass of fermenting beans cannot be obtained without the prior production of acetic acid, there is not a great deal of room for doubt that acetic acid is the primary cause of death, particularly as

acetic acid formation begins almost as soon as that of alcohol. Forsyth (1957) has found that acetic acid is much more toxic to the cocoa bean than ethanol.

Consideration of the cause of bean death is important in relation to the question of prolonging the period of viability. The pulp undergoes considerable alteration during this phase and it may be necessary under such circumstances to take steps to restore the conditions responsible for bean death and subsequent changes.

3. *Alcohol/Acetic Acid/pH/Temperature Complex*

These factors, which form an interdependent complex, must be considered in relation to the conditions required for the anaerobic hydrolytic phase and also for the oxidative phase.

The two factors of direct importance are cotyledon pH, which is controlled by the level of acetic acid development, and temperature, which is raised somewhat by the initial yeast activity but more significantly by the action of the acetic acid bacteria. This latter action is dependent on the prior production of alcohol by the yeasts. Thus it is difficult or impossible to vary one of the above factors without causing significant alteration to the others.

The level of alcohol production depends on the period of yeast dominance and the intensity of yeast activity. These are functions of aeration and the concentration of pulp sugars. Measures which maintain low pulp pH also have the effect of prolonging the period of yeast dominance. This has been achieved by Roelofsen and Giesberger (1958) by the addition of sulphuric acid near the beginning of fermentation.

The rate and level of acetic acid development is related to the concentration of ethanol and aeration. It is mainly produced by the acetic acid bacteria but Roelofsen (1958) has indicated that it is also produced by the lactic acid bacteria. However, as the period of activity of these bacteria appears to be quite short, it is probably a very minor source of acetic acid under normal circumstances. The immediate effects of acetic acid, which rapidly passes through the testa into the cotyledons, are to kill the bean and lower the cotyledon pH. Trials conducted at Keravat (Bridgland, 1959) showed conclusively that there was a consistent inverse relationship between the level of titrable acid and cotyledon pH from the 36th hour to about the 115th hour of fermentation. After this time, cotyledon pH appeared to stabilize and did not follow movements in pulp acid unless conditions of fermentation were altered radically.

In normal fermentations the cotyledon pH at about 115 hours does not alter a great deal for the remainder of fermentation. Thus cotyledon pH is determined by the production of acetic acid during this period. It will be fixed at a higher or lower level according to conditions of fermentation. As a cotyledon pH of 4.5 is said to be optimum for the activity of the glycosidase enzyme (Forsyth, 1957) this is a point of considerable importance.

Theoretically, once it has been determined just when bean death should take place, it would be an advantage to have control over the onset of the acetic phase. It has already been stated that it is possible to prolong the period of yeast dominance which means deferring the acetic phase. Similarly, up to a point, increased aeration in the early stages of fermentation leads to a more rapid onset of the acetic phase. This is in fact the explanation of the observations (Bridgland and Friend, 1957; Rohan, 1957; Howat, 1957) that the top layer of beans in a fermenting box heats up much more rapidly than beans at the centre or bottom of the mass.

The presence of acetic acid in the pulp is also important in maintaining conditions which restrict the growth of putrefying organisms. Titrable acid normally falls rapidly from the beginning of fermentation for 39 or 40 hours and then rises again. The rising trend may continue until the end of fermentation or may level out from about 50 hours depending on conditions (Bridgland, 1959). With appropriate treatment it can be made to show a consistent fall to the end of fermentation (Bridgland and Friend, 1957). The curve produced in all probability represents two intersecting curves —the initial fall in extractable acid representing the breakdown of citric acid and subsequent movements reflecting the level of acetic acid production. As it appears that citric and acetic acids are the only two organic acids of any importance which occur in normal fermentations (Roelofsen, 1958), this explanation would appear to be sound. That citric acid is broken down by yeast activity has been proved

by Roelofsen (1958) by growing yeasts in synthetic media under aerobic conditions where sodium citrate was the sole source of carbon.

It is not surprising, therefore, that the fall in extractable acid at the beginning of fermentation is reflected in sharply rising pH, but as citric acid does not enter the bean (Forsyth, 1957) there is no significant alteration in cotyledon pH. As acetic acid production begins, the rate of rise in pulp pH falls off and after 42 hours cotyledon pH begins to show a sharp drop from its initial level of about 6.2 and falls to about 4.5 after 115 hours' fermentation. Howat (1957) considers that the fall in cotyledon pH cannot be attributed entirely to the uptake of acetic acid by the bean. In a trial conducted at Keravat (Bridgland and O'Donohue, unpublished), fresh beans were depulped, given a quick dip in one per cent. mercuric chloride, well rinsed and buried in a normal mass of fermenting beans in very small plastic bags. These beans were therefore subjected to very nearly normal temperature treatment since the mass developed and maintained a temperature of 48 to 50 degrees C. The beans, however, would not have come into contact with acetic acid. Determinations of cotyledon pH were carried out on beans both from the small bags and from the main mass over a period of five days. The results are given in Table I.

TABLE I

Changes in Cotyledon pH in Absence of Acetic Acid

—	pH Cotyledon		Temperature (Main Mass Degrees C.)
	Plastic Bags	Main Mass	
1st day	6.08	6.11	42
2nd day	5.91	4.55	50
3rd day	5.96	4.74	50
4th day	5.87	4.83	48
5th day	5.80	4.77	47

It is clear that there was no significant reduction in cotyledon pH in the absence of acetic acid. The very small drop shown was probably due to incomplete removal of the pulp and incomplete sterilization.

In most overseas cacao-producing countries, pulp pH shows a steady rise to the end of fermentation. Under New Guinea conditions it usually becomes buffered at about 4.5 after 70 to 90 hours' fermentation (Bridgland, 1959; Bridgland and Friend, 1957). This applies to the standard method of box-fermentation. Where steps are taken to reduce acidity, pulp pH continues to rise towards the end of fermentation. In extreme cases, it has been raised to 7.0 after six days' fermentation (Bridgland and Friend, 1957). Rising pulp pH is almost invariably associated with the more rapid onset of putrefactive changes. It has been found consistently that the higher the level of extractable acid the safer it is to prolong fermentation. Conditions of high acidity are usually associated with poor aeration and, correspondingly, increased aeration, while causing rapid increase in the level of acidity initially, causes a steady loss of acid subsequently. This loss is attributed partly to volatilization at turnings and partly to the oxidation of acetic acid by such organisms as *Acetobacter rancens* (Roelofsen, 1958).

It might be expected that, as the conversion of alcohol to acetic acid is a highly exothermic reaction, a higher level of acidity would always be accompanied by a higher temperature. This does not always conform with the observed facts under New Guinea conditions. The problem here is frequently one of excessive acidity and this is accompanied by depressed temperatures.

The production of a high level of acidity in association with lower temperatures is perhaps explicable in terms of the rate of energy release. If conditions in the sweat-box greatly slowed down the growth of the acetic acid bacteria and at the same time favoured the activity of another organism capable of producing acetic acid at a slower rate, a high level of acidity could ultimately be developed. This however would be associated with lower temperatures due to consistent radiation losses over a longer period. As high acidity and low temperatures are associated with poor aeration, it is possible that such conditions favour the growth of lactic acid bacteria. The conversion of sugars to acetic acid by these organisms through several intermediates (Jorgensen, 1948) suggests a more gradual energy release than would occur with the oxidation of alcohol to acetic acid by the acetic acid bacteria. In fact, poorly aerated ferments do show a slow but consistent rise in acidity to an abnormally high level as compared with well-aerated batches where the initial rate of rise is very rapid but falls rapidly after about three days' fermentation. In the latter case

temperature rise is rapid while in the former instance it is much slower and reaches a lower level.

Excluding abnormal ferments of the type mentioned above, temperature rise in fermenting beans appears to take place in two distinct phases. In the "acetic" phase, temperatures usually rise to 45 to 50 degrees C. within three days and are maintained at this level throughout fermentation. Within certain limits, reduced moisture and excessive aeration will tend to elevate temperatures by a few degrees.

The next phase which does not normally occur in commercial fermentations may be described as non-acetic. There appears to be a fairly sharply defined concentration of acetic acid above which the fermentation will remain "acetic". Temperatures rarely go as high as 52 degrees C. Conditions of alcohol deficiency, reduced moisture and excessive aeration will cause a drop in the level of acetic acid to below the critical level. Temperatures will then rise above 52 degrees C. and may go on rising until a temperature of 65 degrees C. is reached. This was achieved experimentally on a commercial scale at Keravat within six days of the beginning of fermentation. Undue prolongation of any fermentation will lead into this phase when acidity falls to a sufficiently low level. This is the explanation of the temperature curve obtained by Howat (1957) in his 16-day fermentation trial in Ghana.

The non-acetic phase is almost invariably accompanied by putrefaction and should be avoided at all costs.

The temperature pattern during fermentation was studied at Keravat using continuously-recording thermographs. It is interesting to note that the heat losses during "turnings" were much lower than would be expected. Within a few minutes of turning, the sum of top and bottom temperatures was only a few degrees lower than the total just before turning. Following turning, when the position of the beans in the box was reversed, the temperature at the top usually showed a steady rise. Temperature at the bottom remained at its initial level for about one hour, frequently showed a steady fall for six to nine hours and then began to rise. The loss of heat was attributed to an increased rate of convection, due to the improved aeration in the mass of beans, so that the bottom showed a loss and the top showed a gain until settling in the mass restricted air intake.

The responsibility of convection for the drop in temperature at the bottom of the mass was also supported by trials using the method of Rohan and Allison (1958), namely, fermenting in a tier of trays, one on top of the other. The bottom tray was usually some 10 degrees colder than the top tray. If the position of the trays was reversed, the initial temperature gradient from top to bottom was quickly restored. With this technique the effect could be observed in the absence of a corresponding pressure gradient.

4. *The CO_2/Aeration/Moisture Complex*

The CO_2/aeration/moisture factors form an interdependent complex and this complex stands in a direct causal relationship to the alcohol/acetic acid/temperature complex. It is therefore vital to any consideration of the time and manner of bean death. Furthermore, since oxygen uptake by beans during fermentation depends on the availability of oxygen, the CO_2/aeration/moisture complex is of paramount importance to the oxidative as well as the anaerobic phase.

As noted above, the period of yeast dominance, the duration of the lactic phase and the timing and intensity of the acetic phase are greatly affected by conditions of aeration. Therefore, in commercial fermentation, aeration must be controlled. Then, if a period of viability is important, bean death will occur at the appropriate time and temperature and cotyledon pH will then quickly reach their respective optima of 45 degrees C. and pH 4.5.

The problem in New Guinea is usually one of inadequate aeration. For reasons already stated, improved aeration does not lead to a breakdown in the anaerobic conditions prevailing within the bean until necessary reactions within the bean have been completed—this is with the proviso that conditions for these reactions are at or near optimal. Control of conditions during the anaerobic phase presupposes control of the various groups of micro-organisms and in this aeration is a critical factor. Conditions of good aeration at the beginning of fermentation favour yeast activity and if a breakdown of aerobic conditions is avoided, the lactic phase is probably eliminated altogether.

These same conditions, however, favour the acetic acid bacteria and both temperature and acidity rise sharply. This results in rapid bean death. If, during the initial period, aeration is so excessive that alcohol may evaporate rapidly, then viability can be maintained. This leads to the lowering of the level of acidity but temperature development is equally or more rapid when the conditions of excessive aeration and radiation are removed. Manipulation of aeration can in this way prolong the period of viability and then rapidly bring beans to the optimum temperature for glycosidase activity. Cotyledon pH will remain above the optimum unless the period of viability is reduced and more acid produced.

Following the anaerobic phase, aeration continues to exert a controlling influence on temperature and provides a source of oxygen which can at this stage penetrate the bean. Uptake of oxygen by beans can be followed by observing the precipitation of tannins held in solution in the free moisture within the bean. The liquid becomes " muddy " when the tannins are precipitated by oxidation. This is apparent to a limited extent in good fermentations after 72 hours and is very pronounced after 96 hours. From this point onwards, oxygen uptake can be followed by observing the brown ring of cotyledon tissue immediately inside the testa. As more oxygen is taken up, so the thickness of this ring increases. Quesnel (1957) has suggested that the thickness of the brown ring could be used to determine the end-point in fermentation.

In a normal box fermentation, there is usually a very thin brown ring after 96 hours and almost all the beans show some browning after 120 hours. At 170 hours, the degree of browning is usually pronounced. However, at this stage it should be emphasized that in cold, wet ferments the degree of browning at 170 hours may be only very slight and irregular. The results of such batches are invariably poor. Oxidative changes do not necessarily occur during fermentation. Whether they do or not is a function of aeration and temperature. Given a variable extent of oxidative changes during fermentation, the degree of browning could be used as an index of the end-point only under certain specified conditions of temperature and aeration. Otherwise, the limits imposed by the tendency to putrefy will set the end-point.

In box fermentation on the commercial scale, factors which affect the level of aeration of fermenting beans are the dimensions of the mass, external barriers such as box walls, the temperature of the mass and condition of the pulp.

As the volume of beans in a fermenting mass is reduced, particularly in respect of depth, aeration is correspondingly improved. The poor aeration of deep boxes is due simply to the elimination of air spaces between beans, because of pressure. Even in more shallow layers, however, there is an important interaction between aeration and temperature. Evidence given above suggests that the rate of air movement through a mass of beans is dependent on convection. Thus, the higher the temperature the more rapid the air movement. Adequate ventilation of sweat boxes is an obvious necessity.

A significantly higher rate of aeration cannot be obtained in large, deep fermenting boxes except as a result of reduced moisture content of the pulp. The consequent shrinkage of the pulp leads to better aeration. The specific effects of reduced moisture are obscured by the fact that this condition cannot be achieved without at the same time causing other drastic changes in the pulp. It seems likely that moisture balance is important in fermentation. Howat (1957) has shown that there is an apparent increase in moisture content of the cotyledons from 33 per cent. to 39 per cent. during a six-day fermentation and that if fermentation is prolonged for 16 days the apparent increase continues throughout. It is not yet known whether this increase is real. There is no doubt that moisture is extruded by cotyledon tissue during fermentation. If the increase is real, water uptake from the pulp could greatly influence oxygen uptake by the beans. In trials at Keravat, where pulp was subject to great moisture loss as a result of a 36-hour " resting phase ", the production of free moisture within the bean during subsequent fermentation appeared to be unaffected ; but since the treatment led to temperatures of 60 degrees C. and greatly increased aeration the beans were comparatively dry and contained very little free moisture by the end of fermentation. The cotyledons were quite brown.

The role of CO_2 during fermentation is a contentious topic. CO_2 is produced in abundance in the first stages of fermentation by respiration

of the bean, as a by-product of sugar metabolism by yeasts and as a result of citric acid breakdown. The proportions of CO_2 production from the various sources is not known. Wadsworth and Howat (1954) have shown that a single bean fermented under aseptic conditions may produce up to 10 ml. CO_2, but this ceases when the bean dies. The pulp was not removed in these experiments.

In commercial fermentations, Howat (1957) and his co-worker, Powell, have shown that the atmosphere about fermenting beans is frequently above 90 per cent. CO_2. No details are given regarding the points in fermentation when these observations were made. It appears that citric acid breakdown is completed within 48 hours and that respiration by the bean will also have ceased within this period. Having regard to the period of yeast activity and the dramatic decline in the number of micro-organisms in fermenting pulp between the second and third day of fermentation, as discussed by Rombouts (1952), it seems most unlikely that such concentration of CO_2 will continue beyond the third day of fermentation, provided the beans are turned at normal intervals. However, high concentrations of CO_2 appear to be unavoidable in the early stages of fermentation and the proposition that this is harmful to the development of chocolate flavour is untenable. When the beans are turned, it is probably more important to emphasize the positive effect of recharging the atmosphere with oxygen rather than the more negative effect of removing CO_2 which is no more than a dependent component of the CO_2/aeration/moisture complex.

At this stage attention is drawn to the fairly frequent occurrence in the Gazelle Peninsula of New Britain of what have been termed "dead ferments". The extent to which this phenomenon may occur in other parts of New Guinea is not known. It has been impossible so far to relate the occurrence of dead ferments to seasonal conditions. This is made difficult by the fact that seasonal conditions vary tremendously from year to year. The dead ferments sometimes occur during the dry, and sometimes during the wet, season.

In "dead ferments" (and some are not as dead as others), the normal sequence of changes in a sweat box fails to occur. In extreme cases, the temperature has failed to rise significantly after four days and the beans have much the same appearance as when first placed in the sweat box. Following this, temperature rise is slow and irregular and the odour of acetic acid is very strong. Fermentation is necessarily prolonged for up to 10 days but when putrefactive changes make it essential to remove the beans from the box, the beans frequently turn out to be over 80 per cent. underfermented after drying.

"Dead ferments" take place even where the planter is fermenting beans from the same area, using the same harvesting frequency of pods at the same stage of ripeness and using precisely the same fermenting technique in the same sweat boxes as he does with normal ferments.

"Dead ferments" have been produced artificially at Keravat by adding water to the beans at the beginning of fermentation (Bridgland and Friend, 1957). Similar results were obtained by insulating the sweat boxes against air penetration with polythene sheeting. These trials have been reported fully elsewhere (Bridgland, 1959).

It seems highly likely, therefore, that the explanation of dead ferments lies within the CO_2/aeration/moisture complex. It seems certain that the amount and wetness of the pulp about the beans may vary considerably. For two years we have recorded the weight per cubic foot of beans as they reach the fermentary from the field and have found that the weight may vary from 53 to 62 lb. If the difference is mainly due to water, it is equivalent to nearly a gallon of water for every cubic foot of beans. Consequently it is not surprising that beans behave differently at various times of the year. Apart from its effect on aeration, the increased quantity of water will have a very significant effect on maximum temperatures developed. Attention was drawn to this in a previous article (Bridgland and Friend, 1957).

The pulp has been fairly well studied qualitatively. Quantitative studies obviously deserve greater attention. On a recent visit to West Africa, the writer was most forcibly struck by the apparent differences in the pulp between Africa and New Guinea. The squeezing of a few beans taken directly from the pod in New Guinea wrings out a flow of water and soft pulp. Admittedly, observations in Africa were made after the end of the main crop, but both in Ghana and at Mokaria Plantation in the Belgian Congo, the pulp appeared to be much

firmer than in New Guinea. Only a small amount of water and soft pulp could be wrung from a handful of beans. After nine days' fermentation at Mokaria, the beans were dry-ish and did not soil the hand to any great degree. In New Guinea, the hand is left covered by wet broken-down pulp.

The observation that the occurrence of dead ferments is most probably caused by impeded aeration is supported by the fact that they tend to occur more frequently in the very wet areas than in the drier areas. Furthermore, more or less normal fermentation can be restored by reducing moisture and improving aeration. In fact, the occurrence of dead ferments provides an object lesson on the importance of aeration.

The trials in which sweat boxes were lined with polythene sheeting at the beginning of fermentation were most illuminating (Bridgland, 1959). In spite of the fact that the beans were "mixed" or "turned" at 24-hourly intervals, the temperature pattern was drastically depressed and the beans behaved abnormally in every way. It has been proved beyond all doubt that a regular and slow air penetration into the mass of beans is absolutely essential to successful fermentation. It is thought that some of the odd results obtained by fermentation in stainless steel vessels (Howat, 1957) are explainable on the basis of abnormal aeration. Unless the necessary continuous air-flow at the optimum rate were provided, results could be expected to to be poor. The experimental value of such vessels in determining the results given by varied air-flow, is considerable. Similarly, artificial aeration with nitrogen should give a clear answer to the question of whether the presence of CO_2 or the absence of oxygen is the more important factor during fermentation.

Forsyth (1957) has already suggested that one of the main problems in cacao fermentation is the question of balanced aeration. With this, the writer heartily agrees.

FIELD FACTORS AND METHODS AFFECTING FERMENTATION

1. *Stage of Pod Ripeness*

Precise information on the question of the effects of ripeness of pods is not available. Trials conducted by Bridgland and Baseden (Bridgland, 1959) indicated that the harvesting of pods, the skins of which were still partly to half green, resulted in slightly lower temperature development, lower acid development and slightly higher cotyledon pH during fermentation. The trials did not include pods which were so green that the pulp was still firm.

The pulp from under-ripe pods appears to have a higher citric acid content than that from fully-ripe pods, but this effect apparently disappears after 36 hours of fermentation. The slightly lowered acidity throughout the remainder of fermentation is not understood. It could possibly be caused by reduced sugar content of the pulp or by different conditions of aeration due to slightly different pulp texture.

Although the ripe pods gave a more normal pattern of fermentation there was no significant difference in the chocolate flavour development. For a standardized method of fermentation pods should be harvested when fully ripe. There is no possibility of obtaining desirable variation in the pattern of fermentation by departing from this standard.

2. *Harvesting-Breaking Interval*

Information on the effects of the period between harvesting and breaking is scant. The effect is primarily on the ripening process and it would be expected that a comparison of a long interval compared with no interval would be similar to the comparison between fully-ripe and under-ripe pods. This is so. Work done at Keravat (Bridgland, 1959) shows that pods broken on the same day as harvesting show a slightly depressed temperature curve, slightly lower acid development and slightly higher cotyledon pH when compared with other pods with a three-day harvesting-breaking interval. The citric acid content of the pulp seems to be slightly diminished by the three-day interval. It will be noted that in terms of ml. N/10 NaOH per bean the fresh bean from an under-ripe pod required 1.77 ml. for neutralization. A bean from a freshly harvested ripe pod required 1.5 ml. and a bean from a pod harvested three days previously required 1.0 ml. for neutralization. This supports the proposition that citric acid is enzymatically destroyed during the ripening process.

An interval between harvesting and breaking leads to a more normal pattern of fermentation. The limit of this interval is set by the tendency of the pod-rotting organisms to proliferate rapidly in bruise marks and insect-damaged

tissue after four days. Invasion of the pulp by these organisms causes the pulp to dry out and become sugar-deficient. Thus the minimum interval should be three days and the maximum four days. Nothing can be gained by departing from this procedure.

3. *Varying Duration of Fermentation*

Variation in duration of fermentation may vary the extent of essential processes, but not their rate or nature. The factor which is most affected by varied duration is oxygen uptake. It is desirable to achieve the maximum possible oxygen uptake during fermentation within the limits set by the initiation of putrefactive changes. With a given volume of beans and certain specified drying conditions, once the maximum duration is defined there is little room for variation.

When conditions of low temperature and higher than normal acidity are obtained, fermentation can be safely extended with apparent advantage. The grower, however, wishes to operate to a routine and this possibility is not a source of great satisfaction. Experience at Keravat indicates that the prolongation of fermentation is not an effective substitute for the optimum conditions for normal fermentation.

There is an important interaction between duration of fermentation and the volume of beans being fermented. This is discussed below.

4. *Variation in Volume and Dimensions of Fermenting Mass*

These factors exert a powerful influence and are capable of producing radical changes in the mode of fermentation. The effects are obtained primarily through alteration of the rate of air penetration into the mass but also by changing the heat balance sheet.

Experience both in New Guinea and overseas indicates that a major factor in aeration is the depth of beans—not so much the length and breadth of the mass. Beginning for example with a mass of beans three feet deep, aeration improves as depth is reduced. The effect of this is to shorten the period of yeast dominance and to cause an earlier initiation of the acetic phase. This results in a more rapid and more uniform rise of temperature and, since the amount of alcohol produced is reduced, shallow ferments tend to be less acid than deep ferments. Nevertheless, bean death occurs somewhat earlier in shallow ferments. Fermentation is usually faster and more complete. A parallel effect of reduction in depth is the increase of the surface area of the mass in relation to its volume. Consequently heat loss by radiation tends to be greater and this becomes important when heat input by micro-organism activity falls off. Under New Guinea conditions, below a depth of 15 inches the loss of heat by radiation is excessive after three or four days of fermentation. In conjunction with the higher rate of aeration this quickly leads to putrefaction.

Shallow layers therefore have an advantage in the early stages of fermentation but have serious disadvantages in the later stages. The logical step of course is to begin fermentation in shallow layers and complete it in deep layers. This forms the basis of a proposed modification of the standard method of box fermentation presently being used in New Guinea. Details of this method (Method A) and the existing standard method are given in the succeeding article. The effects on acidity, temperature and pH of pulp and cotyledons are given in Figures I, II, III and IV.

If, at the same time as depth is reduced, the total volume is also greatly reduced, the problem of the onset of putrefaction becomes more marked. But, for the first three days, the effects of causing a rapid rise in temperature and reduced acidity are also more pronounced. The tendency to putrefaction can again be overcome by increasing volume as fermentation proceeds. Another method (Method B) has used this principle successfully. In this method, beans are fermented for three days in baskets each containing only 4 cubic feet of beans. These baskets are placed for three days in a "hot box" of black-painted corrugated iron in the sun. The beans are turned each day, one basket in the "hot box" remaining empty to facilitate this. While the method does not depend on it, solar heat aids the rise in temperature. After three days, the contents of 12 to 15 baskets are placed in a standard fermenting box and with daily turning fermentation proceeds for a further four days. The pattern of fermentation is more reliable than with "Method A". The process is again brought within a weekly cycle and this is important to the routine established by the grower.

The effects of this method on temperature, acidity and pH of pulp and cotyledon are shown in Figures I, II, III and IV.

Rohan and Allison (1958) have utilized the principle of fermenting in shallow layers to the limits of its capability with their method of tray fermentation. In this method, beans are placed in trays with slatted bottoms and measuring four feet by three feet by four inches deep. The trays are stacked one on top of the other in batteries of about twelve. The beans are not turned at all during fermentation, which continues for six days. Throughout fermentation, the stack of trays is covered by a tarpaulin bag or sacking to reduce radiation losses. This method overcomes the problem of excessive radiation losses from shallow ferments, but at the same time gives very much improved aeration. The method apparently works well in Ghana. It has been tried at Keravat and the results under these conditions have so far not been encouraging. The different performances of the method under Ghana and New Guinea conditions is probably due to the difference in pulp character mentioned earlier.

In trials with tray fermentation at Keravat, tiers of 12 to 13 trays were used and all specifications were followed in detail. Temperature development was irregular, not particularly rapid, and compared unfavourably with temperatures obtained by other methods developed at Keravat. A temperature of 45 degrees C. was obtained only after three days and then only in the top few trays. At this stage the bottom trays were still at 37 to 38 degrees C. This order of temperature in the lower trays was maintained throughout. The highest temperature recorded (48.5 degrees C.) occurred in the centre of the top tray on the sixth day of fermentation. The temperature gradient of 10 to 13 degrees C. from top to bottom trays is most undesirable. This gradient was quickly restored if the position of the trays was reversed.

In addition to the vertical temperature gradient, there was a less significant horizontal temperature gradient. Six inches in from the walls of the trays, the temperature was usually two to three degrees C. below that of the centre. The effect was more marked closer to the tray walls. This was reflected in altered conditions of pH and acidity. Putrefaction around the edges was evident on the fifth day and a four-inch band of beans was badly putrefied by the sixth day.

Beans withdrawn and dried before the sixth day became hard and flinty and showed a very high degree of purple or white pigmentation. Under New Guinea conditions, the necessity for turning or mixing obviously cannot be escaped. If this must apply to tray fermentation, the one big advantage of the method is lost.

5. *Frequency of "Turning" or "Mixing"*

This factor has been varied greatly in trials at Keravat. Very frequent turning in the early stages of fermentation (two or three times a day) has an advantage in causing more rapid temperature rise. The increased aeration favours the activity of the acetic acid bacteria. Frequent turning towards the end of fermentation depresses temperature and encourages putrefaction. In any case a variation requiring more frequent turning is largely impracticable owing to the greatly increased box capacity required.

In every method of fermentation used at Keravat, daily turning has resulted in a better temperature pattern and lower acidity than alternate daily turning (Bridgland and Friend, 1957). In boxes five feet by four feet by three feet deep, the loss of heat is surprisingly small. Temperature in the top half of the box invariably shows a steady rise immediately after turning and frequently shows a slight fall about 16 hours after turning. Temperature in the bottom half of the box frequently shows a drop soon after turning, followed by a steady rise up to the next turn 24 hours later.

6. *"Resting" Phase*

The term "resting phase" is used for want of a better one but it is not really satisfactory because the beans are in anything but a state of rest. Relatively little variation can be introduced by varying the factors noted above, with the exception of changes in the dimensions of the fermenting mass. By contrast, the use of a "resting phase" can produce radical variation in the behaviour of fermenting beans.

After breaking, the beans are allowed to drain overnight in a box and the resting phase begins at 6 o'clock the next morning. The beans are spread out thinly on a wooden floor in shade, the building being arranged to give

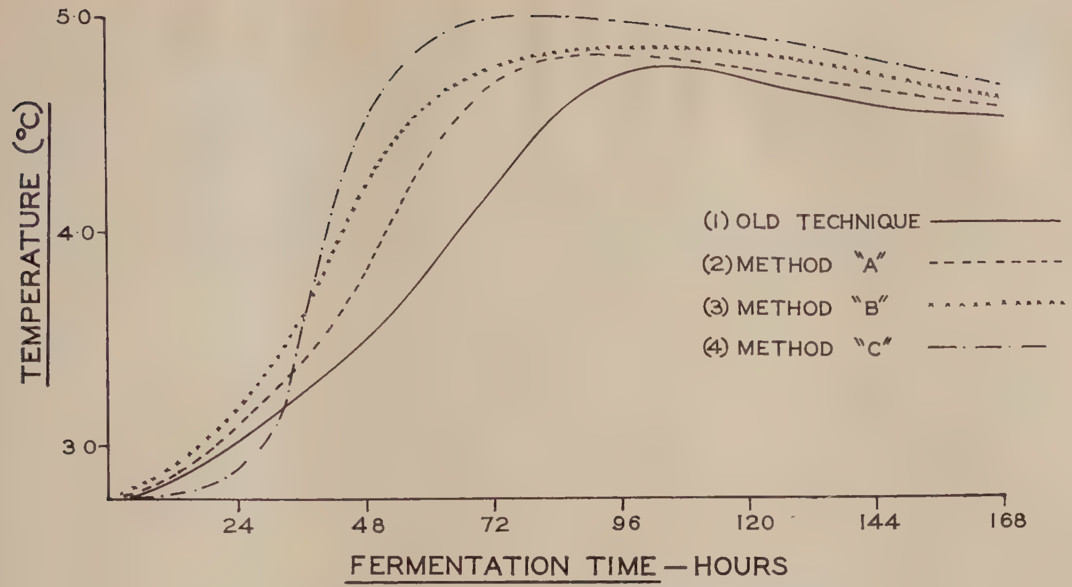


FIG. I.—Methods of fermentation—effects on temperature development.

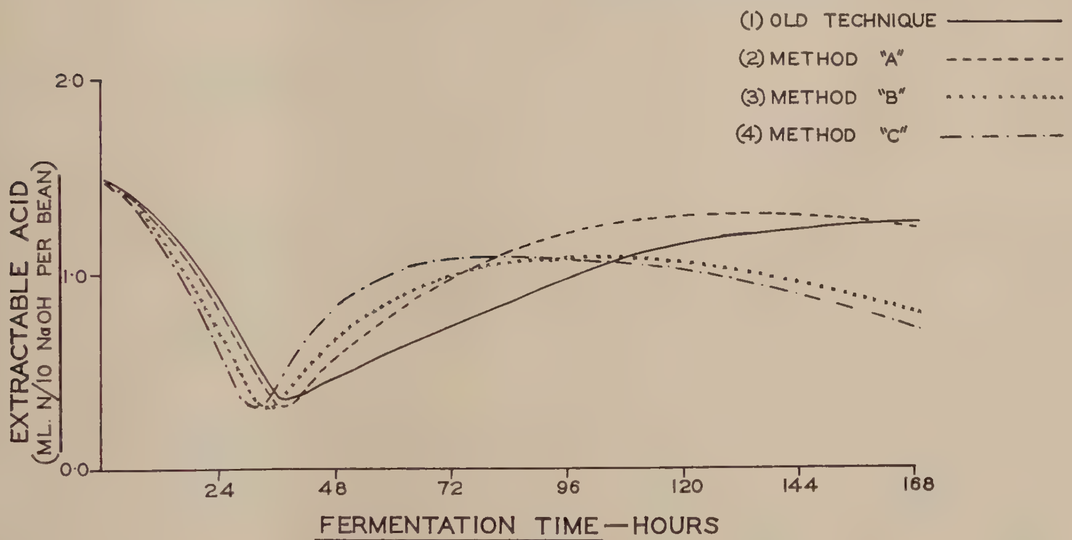


FIG. II.—Methods of fermentation—effects on acid development.

the maximum air-movement across the beans. From time to time, the beans are stirred by "walking".

The resting phase causes rapid maceration and shrinkage of pulp and removal of excessive moisture (Bridgland and Friend, 1957). This leads to greatly improved aeration during subsequent fermentation and a high temperature is developed rapidly. The fact that the level of acidity is depressed considerably indicates the removal of alcohol during the resting phase. The more prolonged the resting phase, the hotter and drier the atmospheric conditions and the thinner the layer of beans, the more pronounced become the effects noted above. With a 24-hour resting phase, temperatures may rise as high as 65 degrees C. by the end of fermentation and acetic acid is virtually eliminated. Foreign flavours are extremely common in this type of fermentation. With a 12-hour resting phase,

temperatures do not rise above 50 to 52 degrees C. and the fermentation remains acetic, but sometimes not sufficiently so to prevent the development of a slight "earthy" character in the beans. It is now apparent that a resting phase of only six to seven hours is sufficient to give the improved aeration which ensures successful fermentation. Following this treatment there is a sharp temperature rise. Acidity is less than in the standard method of box fermentation but quite sufficient to ensure a normal pattern of fermentation without the risk of foreign flavours being developed.

A combination of a short resting phase together with initial fermentation in a shallow box followed by fermentation in a deep box is the basis of "Method C" which is fully described in the succeeding article. The effects of this method on temperature, pH and acidity are given in Figures I, II, III and IV.

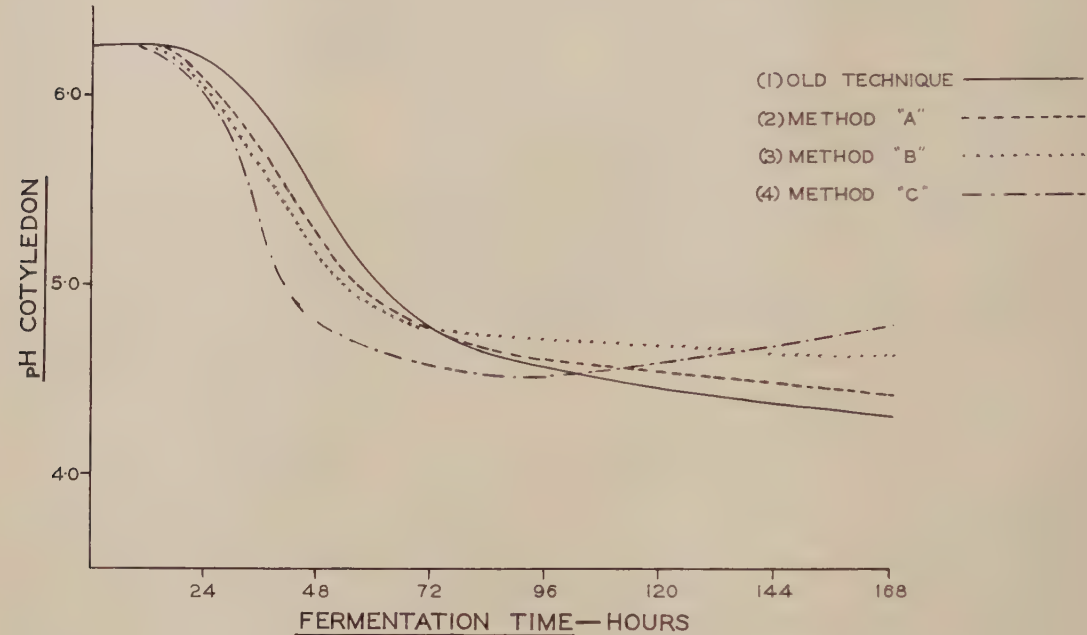


Fig. III.—Methods of fermentation—effects on cotyledon pH.

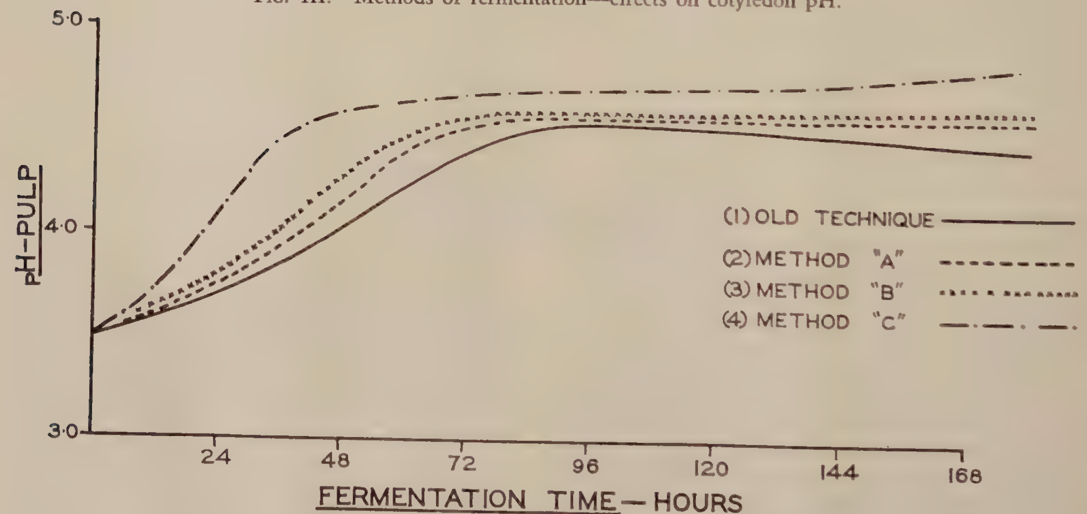


Fig. IV.—Methods of fermentation—effects on pulp pH.

It is apparent that after a long resting phase the pulp is sugar-deficient. It has been demonstrated (Bridgland, 1959, Bridgland and O'Donohue, unpublished), that it is possible to restore a considerably higher level of acidity by adding dextrose or sucrose to the beans at the end of a 24-hour resting phase, or later during fermentation. It would appear, therefore, to be possible to gain control of acidity, temperature and the period of viability by using sugar in conjunction with a resting phase. By this means it should be possible to control all the essential conditions required during fermentation. Encouraging results along these lines have been obtained recently at Keravat (Bridgland and O'Donohue, unpublished) but this approach will probably be ruled out because of the increased costs involved.

The effects of variation of duration of the resting place on temperature, acidity and pulp and cotyledon pH are given in Figures V, VI, VII and VIII.

Very little work has been carried out directly on the effect of a resting phase on microflora. A 24-hour resting phase probably favours the more aerophilic types of yeasts during this period. On return to the sweat boxes there appears to be normal but restricted activity of the acetic acid bacteria. With breakdown of acetic acid and rising pulp pH, fermentation enters the non-acetic phase and temperatures rise to 60 degrees C. or higher. Cultures on yeast-mannitol agar at this stage produced profuse and rapidly growing colonies consisting of large rods, provided culturing was carried out at a temperature of at least 55 degrees C.

As the duration of the resting phase is reduced, the microflora approach "normality". However, when the resting phase is only six to seven hours it is probable that the phase normally dominated by lactic acid bacteria is eliminated.

7. *Ventilation and Insulation*

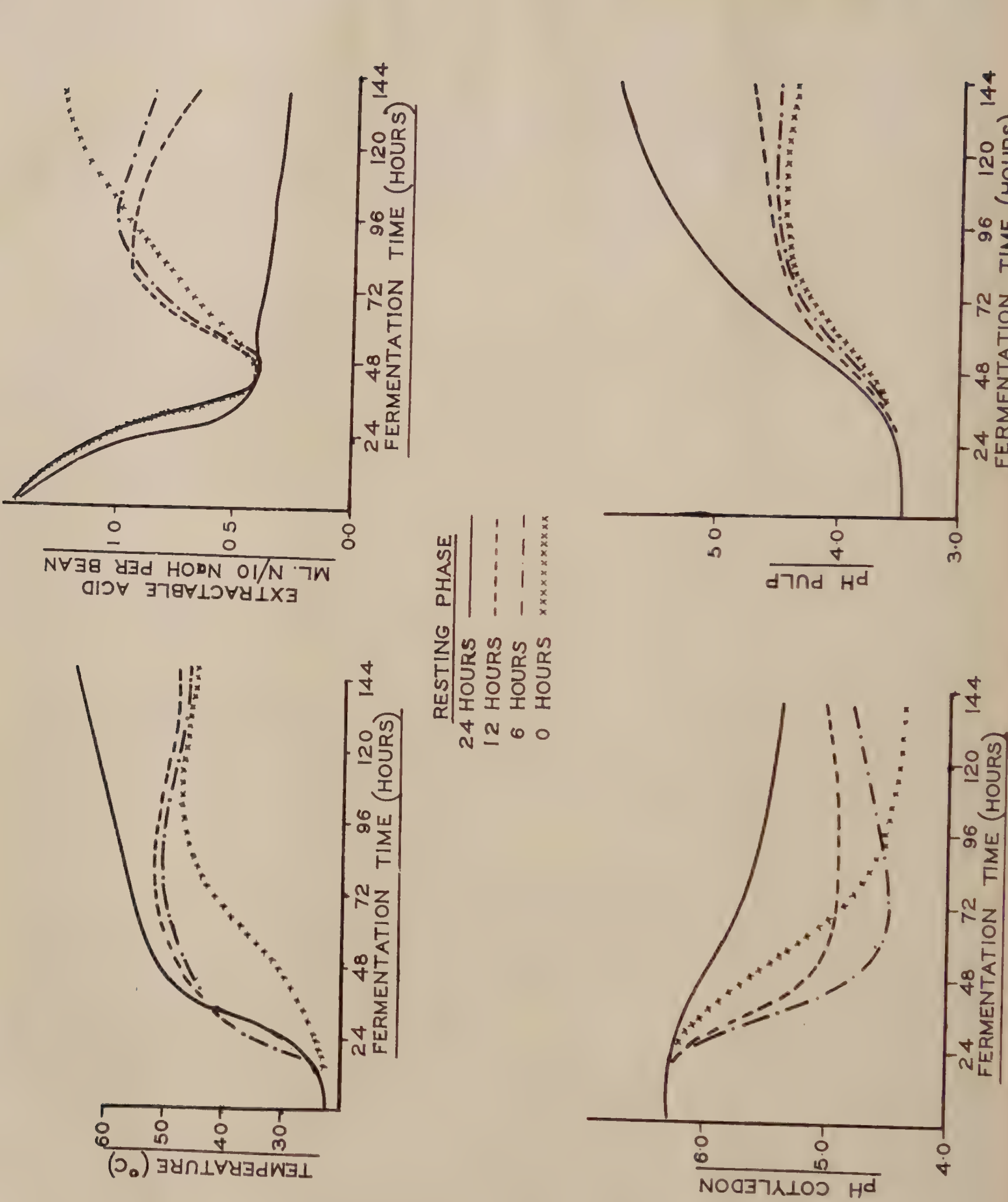
Early trials involving the lining of sweat-boxes with polythene sheeting have been described elsewhere in this article. In these trials, the boxes were lined from the beginning of fermentation and "dead ferments" were produced. The results were disastrous.

In subsequent trials (Bridgland and O'Donohue, unpublished) sweat-boxes were lined with polythene sheeting after the temperature of the mass had risen to 50 degrees C. When the treatment was sustained for 48 hours with a "turn" after 24 hours, there was a steady fall in temperature (10 degrees C. over 48 hours) and a substantial increase in the level of titrable acid. When the treatment was applied for periods of 24 hours on alternate days, the temperature pattern (in time) was not significantly affected, but the tendency for beans in the bottom of the box to show a sharp fall in temperature after a "turn" was eliminated. Two periods of 24 hours in polythene on alternate days maintained a steady and even temperature pattern and caused a noticeable rise in acidity. The technique may be of significance to the inhibition of putrefactive tendencies where fermentation is prolonged or when the level of acidity is low. However, beans tend to develop an odd "carbolic" odour when boxes are lined with polythene. It is by no means certain that the acid developed is acetic acid and the use of polythene sheeting must be viewed with suspicion.

These trials give yet another indication of the controlling influence of aeration and suggest means of preventing ill-effects produced late in fermentation by greatly increased aeration early in fermentation.

The results of Roelofsen and Giesberger (1958) indicate that air ascends through the mass of beans. Work at Keravat fully supports this conclusion. Cool air is taken in through the bottom of the box. During the first three days of fermentation, when micro-organism activity is at its peak, this results in a rise in temperature of the beans at the bottom of the box and a more marked temperature rise in beans at the top of the box. Subsequently, air intake at the bottom of the box has a cooling effect on these beans, while beans at the top are maintained at high temperature. The insertion of a plywood baffle, with no holes, to cover completely the bottom of the sweat box after the third day of fermentation greatly reduced the vertical temperature gradient in the beans. The level of ventilation in the bottom of the sweat boxes was evidently of considerable importance.

Experience at Keravat indicated that there was also air intake through the sides of the box. It is not a point which has been established



FIGS. V, VI, VII, VIII.—Effects of varying the duration of the resting phase

but it would appear that air intake through the sides can lead only to inequalities in aeration in the mass. The point will be checked.

On certain estates in Trinidad, the sweat-boxes are double walled and the intervening space is packed with insulating material. The order of advantage obtained by this procedure is not known.

Trials conducted at Keravat involving the insertion of perforated bamboo tubes into the mass both horizontally and vertically appeared to produce no significant variation in the course of fermentation. They appeared to act as flues through which heat could more readily escape.

8. *Added Chemicals and Water*

The idea of adding chemicals to fermenting beans to produce desired changes is one which has always had great appeal to research workers. It has been approached mainly on the basis of the false assumption that the presence of acetic acid is detrimental. With the object of prolonging the alcoholic phase and eliminating the acetic phase, efforts have been made to prolong the period of yeast dominance and eliminate the acetic phase. Success in achieving this has been reported from several sources, but the results have been such that they can be dismissed as irrelevant.

Work at Keravat is in accord with the view that acidity can be, and frequently is, excessive. Our object is to reduce acidity but not eliminate it. The use of sugar in conjunction with a resting phase as a means of manipulating acidity has been described above.

References are occasionally seen to the addition of water to fermenting beans. Dr. Quesnel has informed the writer that it is a common practice in Trinidad, where about four gallons of water are added after each turning to each 1,000 lb. of wet beans. The object of this treatment is to reduce acidity. The theory is that, as acetic acid is derived from the heat-producing oxidation of alcohol, reduced aeration due to swelling of the pulp will necessarily cause a reduction in both temperature and acidity.

Under standard conditions of fermentation in New Guinea, the reduction in acidity following the addition of water is only temporary. The final effect is to increase the level of acidity and depress the temperature curve. The treatment accentuates rather than solves the problem (Bridgland and Friend, 1957). It seems that under New Guinea conditions any measure which leads to more anaerobic conditions causes a rise in acidity.

Where a resting phase of 24 hours is used, aeration during subsequent fermentation is greatly increased. Moisture in the pulp is also very greatly reduced and it appears possible that this radical alteration in the moisture balance may be unfavourable to the growth of acetic acid bacteria. Trials carried out by Bridgland and O'Donohue (unpublished) showed that under these circumstances the addition of about ten gallons of water at 55 degrees C. per 4,000 lb. wet beans on the fourth day of fermentation did lead to a significant increase in acidity, but did not cause significant alteration in temperature.

9. *Artificial Inoculation*

It is not worth reviewing the work on this subject. Results of work both overseas and at Keravat have produced nothing significant. The general conclusion is that control of micro-organisms can be effected only by controlling conditions. Given the right conditions, the micro-organisms will look after themselves.

CURING/DRYING PROCESS

The handling of cocoa involves a sharp break in technique between so-called "fermentation" and so-called "drying". There should not, however, be a corresponding break in the processes taking place within the bean. That "drying" involves more than dehydration has often been repeated and it is a truism which cannot be repeated enough.

Rohan (1957) has shown that if beans are removed from fermenting heaps to the drying trays at the moment of, or soon after, bean death the breakdown of anthocyanins (strictly part of the "Anaerobic Hydrolytic Phase") continues for some time. Presumably this reaction could proceed only until inhibited by intermediates of the oxidase reactions. This anthocyanin conversion during drying is scarcely a matter of practical importance to the New Guinea grower. For reasons which have already been given, the anthocyanin conversion will be completed during fermentation proper, long before drying commences. Under field conditions, methods of drying need not be considered in relation to this reaction.

Of far greater importance is the fact that the " Oxidative Condensation Phase ", which begins during fermentation, can and must continue during the drying process. Apart from removal of moisture, this is the most significant factor to be considered—hence the term " Curing/Drying " is preferred to " Drying ". Besides the direct influence of the oxidative changes on final quality, there are other effects tied up with the rate of dehydration. It has been shown by Powell and Wood (1957) that rapid drying results in a higher content of volatile acid. The effect implied is that there is a greater loss of acetic acid by volatilization with slow drying than with fast drying. The tendency of the broken-down pulp to putrefy is bound up with its moisture content. Extremely slow drying can thereby result in the development of earthy and foul flavours in the bean. It is usually a matter of good judgment to dry at a rate which will permit the necessary oxidative changes to take place and yet inhibit the growth of putrefying organisms.

The loss of moisture and progress of oxidative changes are accompanied by obvious physical changes in the bean. Before any significant amount of oxidation has occurred during fermentation, the beans have a " crisp-wet " cut. There is considerable softening by the end of fermentation. After one day's sun-drying the beans have a much softer cut and after two days they have a soft, rubbery consistency. With further drying the texture becomes " leathery " and finally the cut is " crisp-dry ". These changes of texture follow oxidative changes and variations in moisture content. The " under-fermented " or under-oxidized bean becomes cheesy instead of rubbery and after drying the cut remains " hard-cheesy ".

These changes are necessarily related to " browning " and the development of the characteristic open texture of a well-fermented bean. Beans at the end of fermentation show varying degrees of browning and the cotyledons should show significant separation. At the end of fermentation, cotyledons can be fragmented between the fingers much more readily than in fresh beans. At the soft rubbery stage, the cotyledons show considerable opening-up and browning. By the leathery stage, the texture is almost that of a fully-dried bean and the cotyledons are, or should be, almost completely brown with perhaps a slight residual purple or whitish cast. From this point onwards, " drying " becomes a simple matter of dehydration.

As moisture is lost from the bean, there is a marked reduction in volume. Not only do the cotyledons shrink but the testa also shrinks about the cotyledon. Measurements by Bridgland and O'Donohue (unpublished) show that there is a 38 to 45 per cent. total reduction in the volume of a mass of beans during drying (see Table II). This reduction is largely accounted for by bean shrinkage but comparison of volume determinations by count per cubic foot against actual displacement shows that of the 38 to 45 per cent. total reduction in volume about three per cent. is caused by reduction in " pore-space " between beans and 35 to 42 per cent. by reduction in individual bean volume. The variation in loss of volume is due to variation in fermentation. With good fermentation beans remain " plumper " and the loss of volume is reduced.

TABLE II.

Reduction in Volume during Fermentation and Drying

Stage	No. Beans/Cu. Ft.	Reduction in Volume
	(approx.)	(per cent.)
Ex-pod	7,000	....
End fermentation	7,650	5 (approx.) (1)
End drying	13-14,000 (2)	43-50

(1) Probably entirely due to maceration of the pulp.
(2) After rotary drying.

1. *The Problem in New Guinea*

Under New Guinea conditions, the problem is usually one of insufficient oxygen uptake. However, abnormally long fermentation and very slow drying do result in over-oxidation and loss of flavour. This effect is accentuated as batch size is reduced. Of more importance to the manufacturer than the loss of chocolate flavour, however, is the fact that such methods invariably result in foetid or foul flavours, which are intolerable.

De Witt (1952) has drawn attention to the fact that in cacao-producing countries generally there is an inverse relationship between fermentation time and drying time. The shorter the fermentation, the more prolonged the drying and vice versa. This can be explained simply

in terms of oxidation. The greater the extent of oxidation by the end of fermentation proper and the more susceptible the bean to oxidative changes, the shorter the drying time can become without detriment to quality. Under the best conditions of fermentation yet devised to suit local conditions, a drying time of not less than four days is required to give the necessary level of oxidation.

The economic implications of this are considerable. Evidently the output from a given fermentary set-up could be quadrupled if drying could be accomplished in one day, assuming that the drying equipment available had a capacity equal to the daily discharge capacity from the fermenting boxes. As the amount of capital invested in fermenting boxes, etc., in relation to their potential output is considerably less than the amount involved in hot-air driers, there would be a considerable saving if fermentation were such that rapid drying would not be detrimental to quality. Work along these lines is proceeding.

Further work with the object of accelerating the rate of oxidative changes during drying is continuing. No very significant results have yet been obtained and no alternative to four-day drying has been found. This is at variance with results obtained by Wood (1957) and with techniques used by Mokaria Plantation in the Belgian Congo and by the United Fruit Company in Costa Rica. In trials conducted by Wood in Ghana, using a modified "Chula" drier, drying was completed in 15 to 24 hours. Sun-dried controls were kept. The conclusion reached was that there was little to choose between sun-dried and machine-dried beans. "The artificially-dried beans had a rather brighter coloured testa", Wood reported. " . . . the nib was dark chocolate brown, there was no sign of brittleness nor were the beans any more wrinkled than normal West African Beans". The writer has observed similar results at Mokaria Plantation in the Belgian Congo where drying is completed in 18 to 22 hours using the "Buttner" dryer. The trials in Ghana followed fermentation in 1,200 lb. lots of wet beans for six days. At Mokaria, much larger boxes were used and fermentation proceeded for nine days.

It is re-emphasized that such rapid drying in New Guinea has given disastrous results. Most of the beans failed to become sufficiently brown and remained cheesy in texture. The different results are probably due to the fact that oxidative changes by the end of fermentation have normally gone further under West African conditions and, more important still, oxygen uptake during the early stages of drying probably proceeds much more rapidly with the thinner-shelled Amelonado beans than with the New Guinea Trinitario (the shell percentage of which is some four to five per cent. higher). Finally, the writer is not at all satisfied that such drying methods do not interfere with flavour development. When trials are conducted over a full cropping season and the results evaluated by a representative panel of manufacturers, the results claimed can be accepted, but in any case great caution is necessary in dealing with Trinitario beans where rapid drying results in a marked weakening of chocolate flavour.

2. *Interrupted Drying/"Post-Fermentation"*

Consideration of the question of increasing the output of artificial driers and thereby reducing costs, raises the question of "post-fermentation". This term is not a good one. It sometimes refers to a "special oxidation period" or "interruption" before or during the normal course of drying. Alternatively, it is used to cover the re-processing of dried beans with a view to causing further oxidation.

As far back as 1908, Schulte-im-Hofe developed a method by which, in the course of drying, partially-dry beans were placed in a box overnight. In this overnight period, moisture loss was prevented and heat was said to have developed and this aided the oxidation process. It was claimed that more browning and better flavour resulted from this procedure. Since then, the method has been elaborated in Venezuela (Vyle, 1949), and in Samoa (Eden, 1953), but the principle remains the same. These techniques are very good and very useful. An interruption of drying is not necessarily costly because the drier can be used for other batches for the period of the interruption and a bottleneck in production can be avoided. Interrupted drying is recommended in the succeeding article as a means of increasing the potential output of hot-air driers. Total drying time, including an interrupted period of two days, extends over a minimum of four days. Thus, actual drying facilities need be occupied by a given batch for only two days. In this way, a compromise is

reached between the necessity for slow drying and the high cost of using a given drier continuously on the same batch over a long period.

Methods of "reconditioning" dry beans, implying retreatment to promote further oxidation have been suggested and tried ever since 1818. Presumably, if the enzymes are not destroyed during drying, itself a very doubtful point, there may be some possibility of doing this, but it is not a question which need concern us here. The only object worth pursuing is to process the bean properly in the first instance and this obviates any necessity for re-processing. "Reconditioning" can only result in reduced returns to the grower. The possibility of reducing skin percentage and improving the external appearance of beans by appropriate methods of "reconditioning" is not questioned, but real gain in quality is unlikely to occur.

"Post-fermentation" or a "special oxidation period" used before drying is completed circumvents the problem of oxidation without actually increasing its rate. However, since these methods involve more handling and more supervision, they are not entirely satisfactory.

3. *Rate of Oxidative Changes*

Limitations on the extent of oxidative changes occurring during fermentation have been discussed above. It was noted that information on the optimum pH for activity of polyphenol oxidase is lacking but experience indicates that browning is more rapid as pH rises from four to above five. Conditions of low pH at the end of fermentation are common in New Guinea where the old standard method of box fermentation is used. Very little can be done about this until beans are removed from the sweat boxes. Roelofsen and Giesberger (1958) have found that fermented beans steeped in water containing calcium carbonate brown more completely than beans steeped in plain water. Such trials are to be repeated at Keravat.

Observations noted above regarding the temperature optimum for the activity of the enzyme polyphenol oxidase are not very helpful, but apply as much during drying as during fermentation.

Moisture content of the beans is a controlling factor during drying. Knapp (1937) states that activity of the cacao oxidase falls off rapidly below a moisture content of 20 per cent. Under New Guinea conditions, rapid removal of moisture greatly increases the percentage of underfermented beans. This means that rapid drying must either interfere with oxygen uptake by the bean in the early stages of drying or the enzyme must be inactivated by dehydration before sufficient oxidation has taken place or the explanation could be in a combination of these factors.

4. *Oxygen Penetration of Testa*

It has already been noted that oxygen uptake during fermentation is likely to be limited mainly by the barrier imposed by the testa. This applies with even greater emphasis during drying. The greater proportion of oxygen uptake apparently occurs during drying, although the mechanism of this is not understood.

Superficially, it appears that oxygen has to enter the bean against an outward moisture flow during drying. Whether it enters in solution or the gaseous phase or both is not known. Roelofsen (1958) claims that, in the early stages of drying, loss of moisture is balanced by shrinkage of the testa and cotyledon tissue and concludes that there is no tendency for air to be drawn into the bean until the final stages of drying are reached. By this time, the enzyme would be inactivated by dehydration. He further concludes, therefore, that the oxygen effective in causing browning must enter the bean in solution in the early stages of drying, and that the gas phase plays no part in the "browning" reactions occurring during drying. This interpretation of events may be partly true—it would probably be quite true under conditions of short fermentation or very rapid drying. It is certainly not argued that oxygen cannot and does not enter the bean in solution during the early stages of drying, but the writer believes that Roelofsen's theory does not cover all observations. It should be understood, however, that these arguments are theoretical and there is little relevant evidence available.

Using an analogy, Roelofsen states that if the cotyledon tissue were rigid like wood any water evaporated from it would immediately be replaced by air. He showed convincingly that the central parts of the bean contained more water than the outer parts and claimed that these central parts showed correspondingly higher shrinkage during drying. It was concluded that, as drying proceeds, the bean, unlike a rigid

piece of wood, would show overall shrinkage and as dehydration proceeded further the central parts would shrink more than the outer parts. Moisture lost would not be replaced by air to the same extent as in the piece of wood. The differential shrinkage would result in a suction force developed at the centre of the bean. This would be resisted by a plump bean owing to its more spherical configuration, but not by a bean which was originally flat. Such a bean would tend to " cave-in " during drying and no central cavity would be formed. On the other hand, a bean which was originally plump and which would resist the suction force would develop a central cavity on drying. Air would necessarily be drawn into the bean but at this stage the oxidase enzyme would be inactive because of dehydration.

This hypothesis does not explain why dried unfermented beans, while showing considerable overall shrinkage, fail to develop anything like a normal cavity whether they are flat or plump to begin with. Nor does the theory explain why all " flat " beans are not " caved-in " nor why such beans frequently do develop an internal cavity. On the other hand, the theory gives a good explanation of why it is easier to " brown " plump beans than flat beans.

Roelofsen's conclusions are based on a moisture gradient from the outer cotyledon tissue to the central tissue noted after two days' fermentation. For this short fermentation his conclusion that browning during drying is largely due to the penetration of oxygen in the dissolved state is probably valid.

As fermentation is prolonged to six days or more, cotyledon tissue shows progressive shrinkage. This shrinkage is largely away from the centre of the bean. After two days' fermentation the cotyledons show some slight and irregular separation. After six days the cotyledons may have separated by as much as a millimetre. This suggests a steady extrusion of moisture from cotyledon tissue during fermentation, and this is supported by observation. After six or seven days' fermentation the moisture gradient may have almost equalized. At all events, the central cavity, or at least large central interstices, are usually formed before drying commences and in reality loss of moisture must be considered in relation to two separate halves rather than from a single cotyledon unit.

The removal of moisture from the bean during drying should be considered in two phases, firstly, the removal of free moisture held within all interstices and, secondly, the removal of moisture from cotyledon tissue. The moisture content of cotyledon tissue will scarcely be affected until all free moisture is removed. Removal of free moisture may be reflected by shrinkage of the testa but not the cotyledon tissue. Shrinkage of the testa will be resisted to some extent by cotyledon structure, regardless of its shape, and there will be a tendency for air to be pulled into the central interstices of the bean as moisture is evaporated and before the moisture content of cotyledon tissue shows a significant fall. The more pronounced the interstices and the greater the content of free liquid, the greater the tendency to pull air into the bean.

Under these circumstances, oxygen in the gas phase would be of paramount importance in promoting browning quite apart from the effects of penetration of dissolved oxygen. It is a matter of common observation, at least under New Guinea conditions, that when beans are placed on the drying floor there is usually a brown ring of outer cotyledon tissue due to oxygen penetration in the dissolved state during fermentation. After a six-day fermentation, the browning which occurs during drying does not represent a continuation of this effect. A significant increase in browning first becomes evident about the radicle channel and then extends to the centre of the bean and outwards along folds in the cotyledon tissue. The soft-celled radicle shows the greatest apparent differential shrinkage subsequent to the evaporation of free moisture. Observation on the course of browning suggests that air is drawn into the bean along the radicle channel, the tip of which coincides with the thin, spongy testa tissue at and around the hilum.

This will occur only if there has been adequate shrinkage of cotyledon tissue during fermentation. Otherwise Roelofen's theory will operate, a suction force will be developed, flattish beans will cave in and air intake and browning will be inhibited unless drying is so slow as to permit sufficient uptake of dissolved oxygen.

In the normal course of drying, provided that large liquid-filled central interstices have developed by the end of fermentation, air will be drawn into the bean to replace moisture loss

and browning will be rapid and complete. This generally seems to be a more acceptable explanation than postulating the penetration of oxygen in the dissolved state in the opposite direction to the flow of moisture.

As drying proceeds, cotyledon shrinkage would be expected to take place more or less uniformly and the internal cavity would become "fixed" whether the bean was plump or flattish to begin with. Shrinkage would take place both towards and away from the imaginary central point in the bean. A suction force about the imaginary central point would not be developed.

As a theory, this explanation closely fits the observed facts and explains the reason for the widespread inverse relationship between fermentation time and drying time. The important divergence from Roelofsen's theory is the rationalization of the uptake of oxygen in the gas phase before the enzyme polyphenol oxidase is inactivated by dehydration.

The theory assists in explaining the divergent results obtained from rapid drying under varying conditions. If there has been sufficient preliminary shrinkage, rapid drying will not be expected to cause "caving-in" or to interfere unduly with browning. But if this is not the case, rapid drying will cause "caving-in", prevent further air intake, inhibit browning and shrunken "under-fermented" (or "under-oxidized") beans will result. This has usually been the result of rapid drying in New Guinea.

The theory has considerable significance in explaining the presence of purple beans. If the normal shrinkage of cotyledon tissue during fermentation runs parallel with anthocyanin destruction, then incomplete destruction can be expected to lead to the occurrence of purple beans even though the anthocyanins themselves are susceptible to oxidation. Their presence would be a symptom of inadequate shrinkage by cotyledon tissue. Both Roelofsen and the author have noted that this effect can be overcome by piercing. This removes the possibility of a suction force developing even if there has been little cotyledon shrinkage at the time of piercing. In terms of air penetration, piercing at an early stage of fermentation achieves much the same result as prolongation of fermentation, but more rapidly.

The theory is also relevant to the question of accelerating oxidation. Work on this question would be assisted if the mechanism of oxygen penetration of the bean were understood.

Whether the above theory is tenable or not, other factors which may influence the rate of oxygen penetration are the permeability of the testa and temperature. Efforts to increase the rate of browning by varying drying temperature have so far led to no significant results. In these trials a rotary drier is being used with provision for the recirculation of moist hot air; in this way, the effects of higher temperature are not obliterated by the faster drying time. This work is still in its early stages and is continuing.

Efforts to vary the permeability of the testa have given more promising results but there are serious disadvantages in methods which have so far been tried. In one series of trials at Keravat (Bridgland and O'Donohue, unpublished), fermented beans were steeped in water at 25 degrees and 55 degrees C. for five and 60 minutes. Some were thoroughly washed and all were then rapidly sun-dried in four days.

It was found that steeping in water at 55 degrees C. for 60 minutes and thorough washing resulted in what to the trade would be a significantly higher proportion of brown beans (improvement of 44 units on our method of scoring or a difference of 11 per cent.). The beans which were steeped in water increased in volume (plumpness) by seven per cent. whereas the washed beans, although quite plump, decreased in volume by eight per cent. The loss in volume in washed beans is thought to be due to the removal of all pulp, plus the outer layers of the testa, and perhaps to greater total shrinkage but without "caving-in". With both treatments there was a reduction in shell percentage amounting to approximately 4.5 per cent. with the washed beans and 2.5 per cent. with the beans steeped in water for an hour at 55 degrees C. The beans steeped in water were more brittle than the controls, but not to the extent where this would be of practical importance. On the other hand, the beans which had been washed were extremely brittle.

Steeping for one hour at 55 degrees C. caused a lowering of cotyledon acidity (pH 4.94) compared with steeping for five minutes at 25 degrees C. (pH 4.75). The pH of washed beans remained unaltered (pH 4.76). As the washed beans dried out much faster than the others, this may simply be a rate of drying effect.

Taken overall, steeping at 55 degrees C. made considerably more difference than steeping at 25 degrees C. and steeping for one hour had a greater effect than steeping for five minutes. The effects of the various treatments on flavour have yet to be determined.

The above results are in substantial agreement with those of Roelofsen (1958) who found that steeping beans in water for two hours before drying yielded plumper and browner beans. The effect was attributed to an increase in shell permeability as a result of loss of soluble matter.

Steeping involves more equipment, more handling and more supervision. Washed beans also have the serious disadvantage of being very brittle and will not ship without considerable shattering. This is not regarded seriously by those manufacturers using continuous roasters, but is regarded as a major defect by the majority who are still using drum roasters. "Steeped" beans are not so brittle as washed beans. More work is required before the value of these techniques can be properly assessed.

Mechanical factors may play a part in limiting oxygen uptake by the bean. Where beans are dried entirely in a rotary drier, experience at Keravat suggests (but this is not certain) that the smearing action by which pulp becomes uniformly distributed over the bean tends to seal the bean against oxygen penetration and leads to a slightly higher proportion of under-fermented beans. This effect was accentuated by adding a small quantity of odourless oil to the fermented beans. This was done with the object of preventing clogging and in this it was successful, but the practice cannot be recommended in any form.

In the course of work described above, it has unfortunately not been possible to carry out detailed micro-biological and chemical investigations. It is hoped that this will be rectified at some future date.

It must, however, at least be evident that the processing of cocoa beans, while involving only simple principles, is quite complex in the interplay of controlling factors. "Hit or miss" methods have been used in the past and at best these methods give only partial development of the flavour potential of cacao beans. We require methods that will develop this potential fully. The best methods recommended in the succeeding article are not perfect but they go a long way towards achieving this object. This paper will have served its purpose if the grower is convinced that the fermentation and drying of cacao are matters worthy of infinite care and attention.

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The programme covered in this article has been carried out as a matter of Departmental policy, and the work will continue.

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Plates 1 and 2 were kindly provided by Cadbury-Fry-Pascall Pty. Ltd.

GLOSSARY OF TERMS

It has been impossible to avoid the use of technical terms in this article and the brief notes given below may assist growers who have a more detailed interest in the process of curing.

Anaerobic.—Indicates absence of oxygen in any set of conditions, as distinct from "aerobic" where oxygen is present.

Anthocyanins.—A general term covering a large group of glycosides occurring in nature as plant pigments.

Chocolate Flavour Score.—In trials at Keravat, skilled "tasters" employed by manufacturers are asked to award a score on the strength of chocolate flavour according to the following scheme :—

No chocolate flavour	1
Weak chocolate flavour	2
Fair chocolate flavour	3
Good chocolate flavour	4
Very good chocolate flavour	5

Condensation.—The reverse process to a hydrolysis, i.e., the linking of two or more molecules with the elimination of water. Such reactions are frequently catalysed by enzymes.

Cotyledon.—The intricately folded and interlocked, fleshy primary leaves which account for the greatest part of the bean. This tissue, which is referred to as "nibs" in dry cocoa, contains the substances which are responsible for the development of chocolate flavour. They are white in the case of Criollo beans and purple in the case of Forastero beans. The embryo tissue is not pigmented.

Criollo/Forastero.—Two terms covering the two main types of cacao. Since the proportion of the various polyphenolic substances are different in the two types, they yield different flavours on processing.

CO_2.—The gas, carbon dioxide.

Chromatography.—A fairly recently developed and very useful analytical technique by which complex mixtures or organic substances can be separated.

Ethanol.—Ethyl Alcohol.

Enzyme.—Complex organic compounds which catalyse a great number of chemical reactions occurring in organic tissues.

Fermentation Score.—After drying, beans are cut and divided into five categories which are weighted according to the extent of purple or white pigmentation as follows :—

Per 100 beans—

(1) No. Wholly purple or white beans—X4
(2) No. beans 75 per cent. purple or white ....—X3
(3) No. beans 50 per cent. purple or white ....—X2
(4) No. beans 25 per cent. purple or white ....—X1
(5) No. wholly brown beans .... —

TOTAL—Fermentation Score

A completely unfermented sample would thus score 400 and a completely brown sample would score 0. Experience shows that the strongest chocolate flavour is associated with a score of 40 to 80.

Glycoside.—Compounds formed by the combination of one or more sugar molecules with other substances, frequently polyphenols and tannins. An anthocyanin is one such example.

Hydrolysis.—A type of chemical reaction catalysed by a large group of enzymes and involving the addition of the elements of water to a molecule with consequent separation of the latter into two or more simpler molecules.

Polyphenols.—A broad term used in this article to cover a complex group of substances with a similar basic structure, including the pigments (anthocyanins), tannins, etc. Non-glycosidic polyphenols are those to which no sugar molecules are attached. When the glycosides are hydrolysed and the sugar molecules split off the parent molecule, polyphenol aglycones are formed.

Precursor.—" Precursors " of chocolate flavour do not give chocolate flavour as such. The " precursor " is the building block from which the compounds with actual chocolate flavour will be developed.

Radicle.—The primary root. This lies between the cotyledons towards one end of the bean.

Testa.—The skin of the bean.

Titrable Acid/pH.—" Titrable Acid " refers to the total amount of acid present. " pH " is a measure of the degree or intensity of the acidity or alkalinity of a solution. Low pH means high acidity. At pH 7.0 a solution is neutral. High pH means high alkalinity.

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Figure 1: Yields of Palms in New Ireland Field Trials.

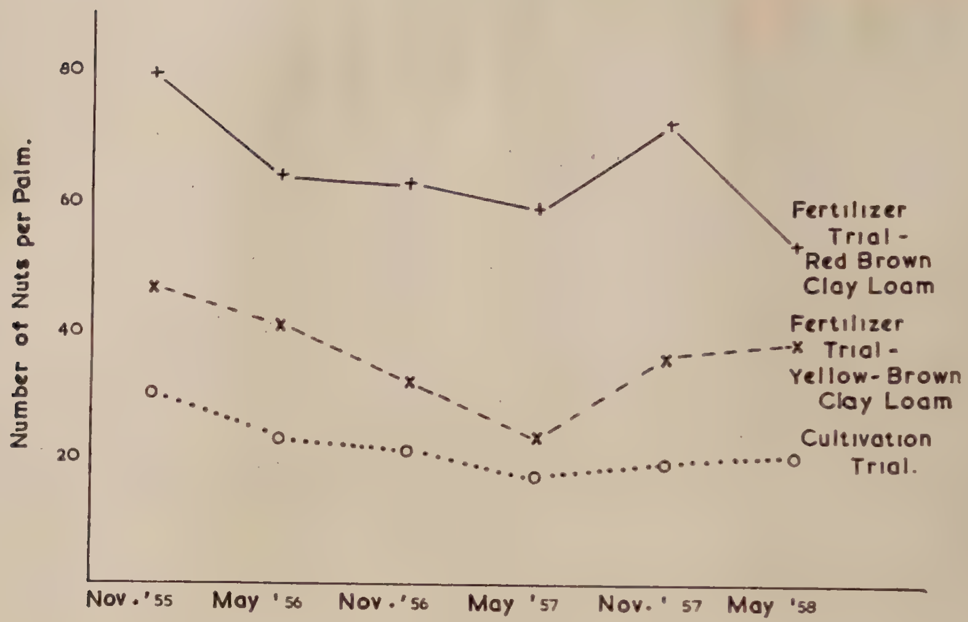
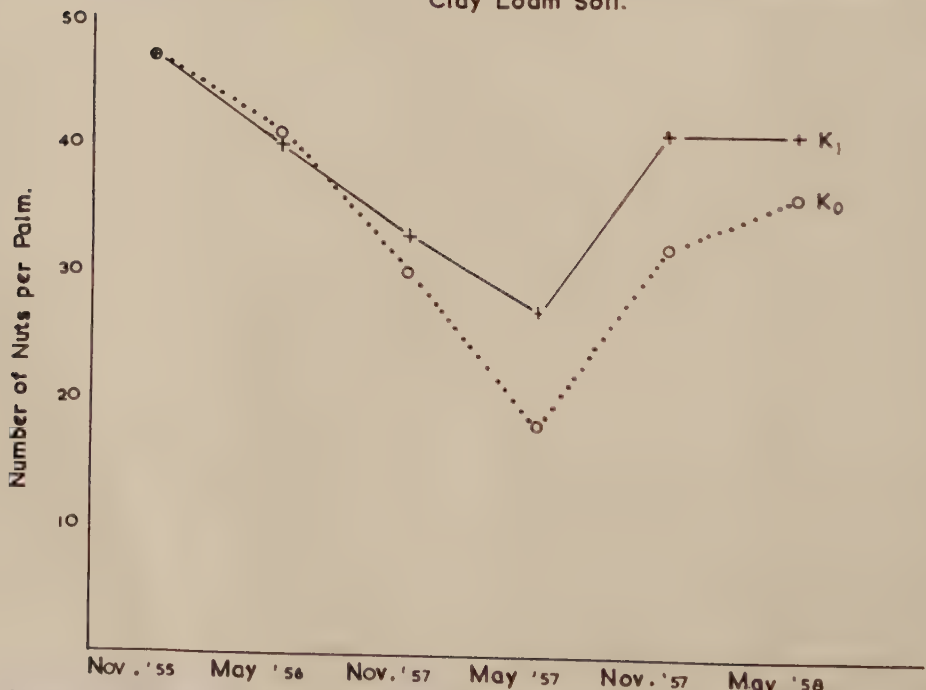


Figure 2: Response to Potassium of Coconut on Yellow-Brown Clay Loam Soil.



Coconut yield figures in New Ireland trials [see "Coconut Experiment Work in New Ireland, Part II"—"Progress report on field trials" (Vol. II, No. 4)].

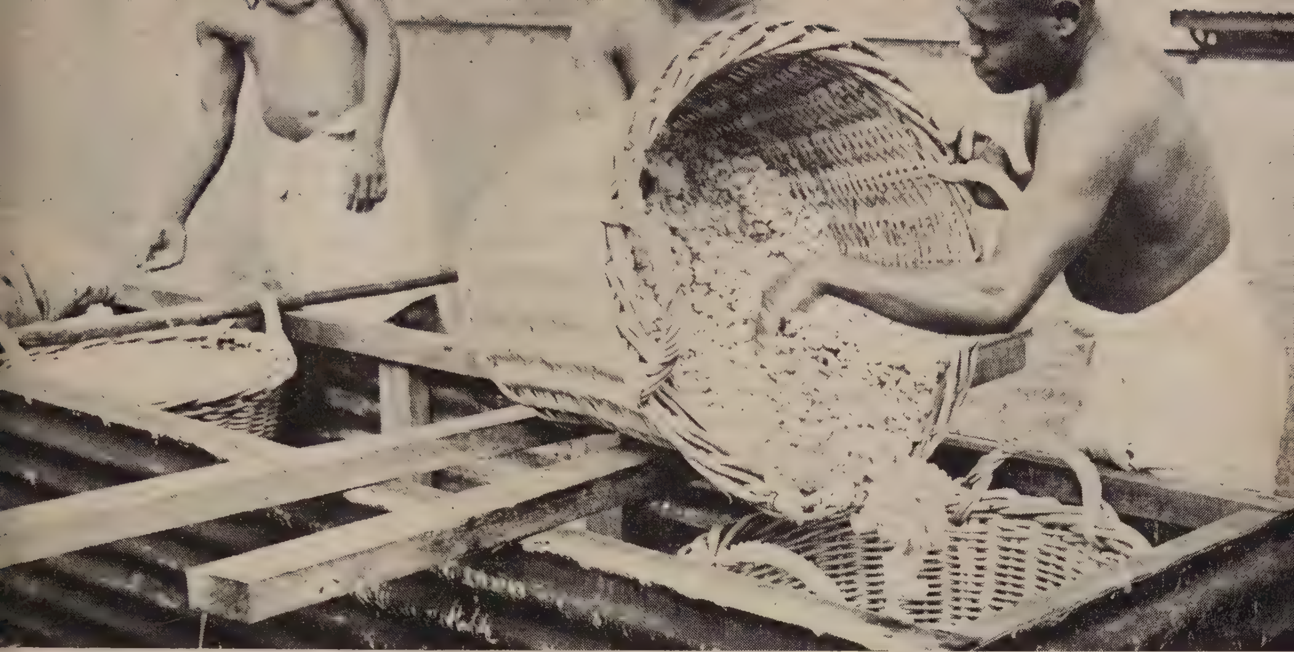


PLATE 1.—*"Basket-box" method of fermentation—beans being transferred from one basket to another.*

PROCESSING METHODS FOR CACAO GROWERS IN PAPUA AND NEW GUINEA

L. A. BRIDGLAND.

In this article, Mr. Bridgland discusses cacao processing from the point of view of the individual cacao grower. He tells how to organize picking, and describes different methods of processing and the stages involved. Mr. Bridgland also describes several variations of a new method of processing beans to give an improved and consistent product and goes into the organization and construction of a fermentary to handle the work.

THE soils and climate in the cacao-growing areas of Papua and New Guinea, in conjunction with the hybrid "Trinitario" type which is grown, contribute to the considerably higher average yield obtained in New Guinea as compared with overseas cacao-producing countries. These same factors, however, are associated with the greater difficulty in processing in a way which guarantees good and uniform development of chocolate flavour.

The object of work on this subject at Keravat has been to devise reliable methods of processing which regularly ensure the production of high-quality beans. Information obtained as a result of work, both here and overseas, on the principles involved in fermentation and drying is contained in the preceding article. This paper will summarize the application of this information and the recommendations of the Department of Agriculture, Stock and Fisheries.

FIELD OPERATIONS

Plantation field operations, which involve harvesting, gathering, breaking and transport of the wet beans to the fermentary, should remain the same no matter which method of processing is used. All field operations should be completed in four or five days.

Harvest (Day 1)

Complete the harvest for a given batch in a single day. All beans will then be in a uniform state at the commencement of fermentation. The practice of harvesting small quantities over a period of a week and then fermenting them together is unsatisfactory.

All trees should be harvested at three- or, at the very most, four-weekly intervals. During the flush-crop it is frequently necessary to harvest all trees weekly to keep pace with the crop. If the interval between harvests is prolonged, losses through disease and germination within the pod will be severe. Records at Keravat (Van Velsen, unpublished) show conclusively that losses from "Black Pod" increase from an average of about 5 per cent. to about 15 per cent. if the interval between harvests is prolonged from three to five weeks. Such losses cannot be ignored.

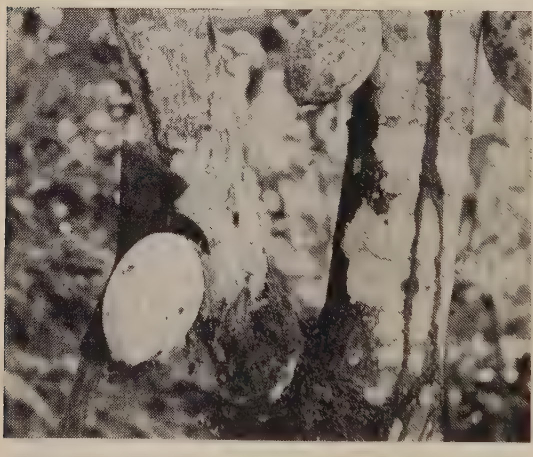


PLATE 2.—*Pods should be cut cleanly with sharp harvesting hooks.*

During actual harvesting, hooks should be kept razor sharp so that pod-stalks are cut cleanly and not torn away from the branch. Only fully-ripe pods should be harvested. Maturity of pods is indicated by colour changes. These changes are variable in the hybrid type of cacao grown in Papua and New Guinea. Common colour changes are from green (immature) to yellow (mature), dull red to bright red and red/green to, orange/yellow. With a little experience, labourers have no difficulty in recognizing mature pods. A slight green colouration around the very butt of the pod is not an indication of immaturity. The type of pod and its colour have no significance during fermentation.

At all harvests, sufficient trees should be picked to ensure a yield of enough beans to give a minimum depth of 15 inches or a maximum depth of 2 feet 9 inches of beans in a number of fermenting boxes.

In the course of all harvests, diseased pods must be removed from the trees. The question is often raised as to whether these diseased pods should be left on the ground under the trees or removed. The two main organisms to be considered are *Phytophthora palmivora* (black pod) and *Botryodiplodia theobromae* (brown pod). In the former case, the spores are carried about by "splash" only. There is some evidence that diseased pods lying on the ground can infect pods or flowering cushions within about two feet of ground level. A "black pod" hanging near the top of the tree could, of course, infect a large part of the tree. The spores of *Botryodiplodia* are wind-borne, but the organism does not produce spores immediately on the newly-rotting pods as does *Phytophthora*. Spores are produced only when the pods are well-rotted and even then they do not have the same ability to penetrate undamaged pods as do those of *Phytophthora*. Until more is known about the subject, present experience indicates that the safest course is to remove diseased pods from the plantation; but failure to do this would not be expected to lead to outbreaks of epidemic proportions.

Because of the skill and reliability required for efficient harvesting, it will pay the grower to hand-pick his harvesting gang and use it consistently.

Gather-Heap (Days 2, 3 or 4)

There is no necessity to "gather" as the pods are harvested, but there is no objection to this. The manager should mark out convenient "breaking" points, so that long cartage of pods is avoided and pod-skin disposal facilitated. Heap the pods at these points. Heaping should be completed by the end of Day 3 or Day 4.

Break-Cart (Day 4 or 5)

There should be an interval of three or four days between harvesting and breaking. A shorter interval should be avoided. An interval longer than four days will often cause serious losses through pod diseases and germination of beans within the pod. It may also interfere with fermentation.

Discard any diseased pods in which the pulp is visibly affected and any pods in which the beans have germinated. Pods should be broken with short, heavy sticks rather than knives, as there is a risk of cutting and damaging the beans. It is usually better to divide the labour between those cracking the pods and those extracting the beans and placenta or pith, which is discarded.

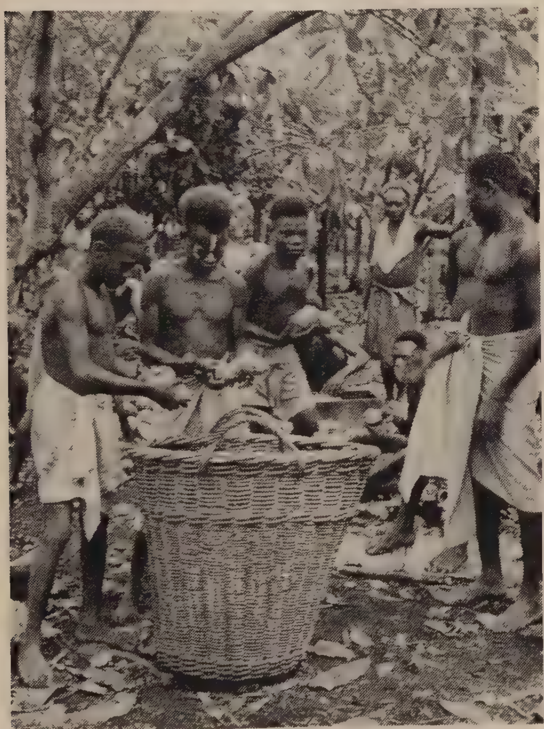


PLATE 3.—*Pods being broken into special baskets on plantation.*

The pods should be broken into boxes or baskets which can be kept reasonably clean. The practice of breaking into foul-smelling, mouldy bags is both inconvenient and detrimental to fermentation. Do not allow beans to become affected by rain during breaking and cartage.

For the most part, the spread of disease does not enter into the question of pod-skin disposal, except, as noted above, that high heaps of rotting skins could increase the rate of "black pod" infection. It is recommended that pod skins be spread around the plantation whenever it is economic to do so. With tropical soils, any form of mulching will be valuable. Skins rapidly decay if left on the surface of the soil and most of the useful elements released by this decay will be leached into the soil. If pod skins are buried, they resist decay and there is no particular virtue in this procedure.

On plantations which are well served with roads, it may be possible to shift breaking points regularly and this avoids any problem of excessive accumulation. Where this cannot be done and where skins cannot be redistributed, they should be thrown into natural depressions, gullies or creeks. This will prevent the accumulation of high heaps of skins. The economics of dispersal of skins will largely depend on soil fertility. On marginal soils, the order of benefit from this practice will be much higher than on the very fertile soils.

The question is sometimes asked whether the spreading of pod skins is likely to encourage or spread the root-rotting fungi. Generally speaking, the spread by spores of the diseases which occur in New Guinea is very limited, especially if diseased trees are dug out and burnt as soon as infection becomes evident. If this is done, the organisms will generally have insufficient time to release spores. Pod skins are most unlikely to become infected from this source before they decay and there is no risk at all once the tissue is dead. The root-attacking fungi which concern the cacao planter usually spread by rhizomorphs or threads growing along living roots in the soil. Heaps of pod skins could become infected only if there were a soil infection to begin with. If this were so, cacao trees would in all probability become infected sooner or later, whether there were pod skins about or not.

METHODS OF FERMENTATION

Existing Methods

Present methods of fermentation in Papua and New Guinea vary considerably but for convenience in description they are lumped under the term "Old Technique". In its most common form, this consists of placing the wet beans in wooden sweat-boxes, usually 5 feet long by 4

feet wide by 3 feet deep. Fermentation proceeds for six and three-quarter to eight and three-quarter days (usually seven and three-quarter days) with daily or alternate daily turning, according to the particular plantation and the time of the year.

The results of this method are variable. They are sometimes good and sometimes poor, but are usually irregular in respect of apparent quality as judged by the "cutting test" and of real quality as judged by the flavour of chocolate made up from the beans. Chocolate flavour varies from complete absence to good strength. Side-flavours such as liquorice, caramel or raisin, which frequently but not invariably accompany weak chocolate flavour, are usually pronounced. Excessive acidity frequently constitutes a serious defect.

Objections to "Old Technique"

The irregular flavour development noted above can be traced to variation in temperature and acidity during fermentation. These factors may not be brought to the optimum conditions required for the development of the precursors of chocolate flavour, or these conditions may be developed only very slowly during fermentation, necessitating prolonged fermentation. Long ferments are also made necessary by the wide variation in the conditions within the sweat-box. To produce beans which have the appearance of being well-fermented, processing must be continued for so long that flavour is frequently lost by over-oxidation.

Variation in the pattern of fermentation using the "Old Technique" largely reflects variation in the pulp at the start of fermentation. This pulp variation is pronounced in the Gazelle Peninsula of New Britain. "Dead Ferments" (those in which temperature fails to rise or rises only very slowly to a sub-optimal level) cannot be avoided. These frequently lead to even longer fermentation and putrefaction. Beans resulting from this treatment sometimes develop the appearance of being well-fermented, but may completely lack chocolate flavour and may possess a variety of defective flavours.

If, in any part of the Territory, results from the "Old Technique" are not consistently good, growers are advised to scrap the method in its present form. For those who feel that they must retain it, the following points should be noted :—

(1) Daily turning usually results in better temperature development and slightly lowered acidity, as compared with alternate daily turning.

(2) The bottoms of the boxes used for the first three days of fermentation should be drilled with half-inch holes on a two-inch-square pattern. For boxes used for the remainder of fermentation, drill holes only on a six-inch-square pattern.

(3) Better results will be obtained if sweat-boxes are not filled to a greater depth than 2 feet 6 inches.

(4) A fixed duration for fermentation cannot be set. The grower should be guided largely by the odour of the beans. When the vinegary odour diminishes and when signs of putrefaction begin to develop in the corners, on the sides and bottoms of the fermenting boxes, turn the beans out to dry. On no account should fermentation be continued. Fermentation should never last longer than eight days.

METHOD "A"—"*Modified Old Technique*"

This method involves only a slight departure from the "Old Technique". Two different fermenting boxes are required. Fermentation begins in boxes 5 feet by 4 feet by 1 foot 6 inches deep on the fourth day after harvesting (i.e., on Day 5). The beans are turned at 8 a.m. on Days 6 and 7. At 8 a.m. on Day 8 (i.e., after almost three days in the shallow boxes), the contents of two shallow fermenting boxes are turned into a larger box, 5 feet by 4 feet by 3 feet deep. Fermentation continues in this type of box for a further four days (i.e., Days 9, 10, 11 and 12) with daily turning. Thus, fermentation is completed in seven days, bringing the process within a weekly cycle. The beans are then turned out to dry.

Fermenting Boxes Lay-out and Design

The possibility suggests itself of having a single battery of the shallow fermenting boxes of greater length and breadth (say 10 feet by 4 feet by 1 foot 6 inches or 8 feet by 5 feet by 1 foot 6 inches deep) instead of the double battery of smaller dimensions (as in Diagram I). There is no objection to this, but "turning" is facilitated in the smaller boxes.

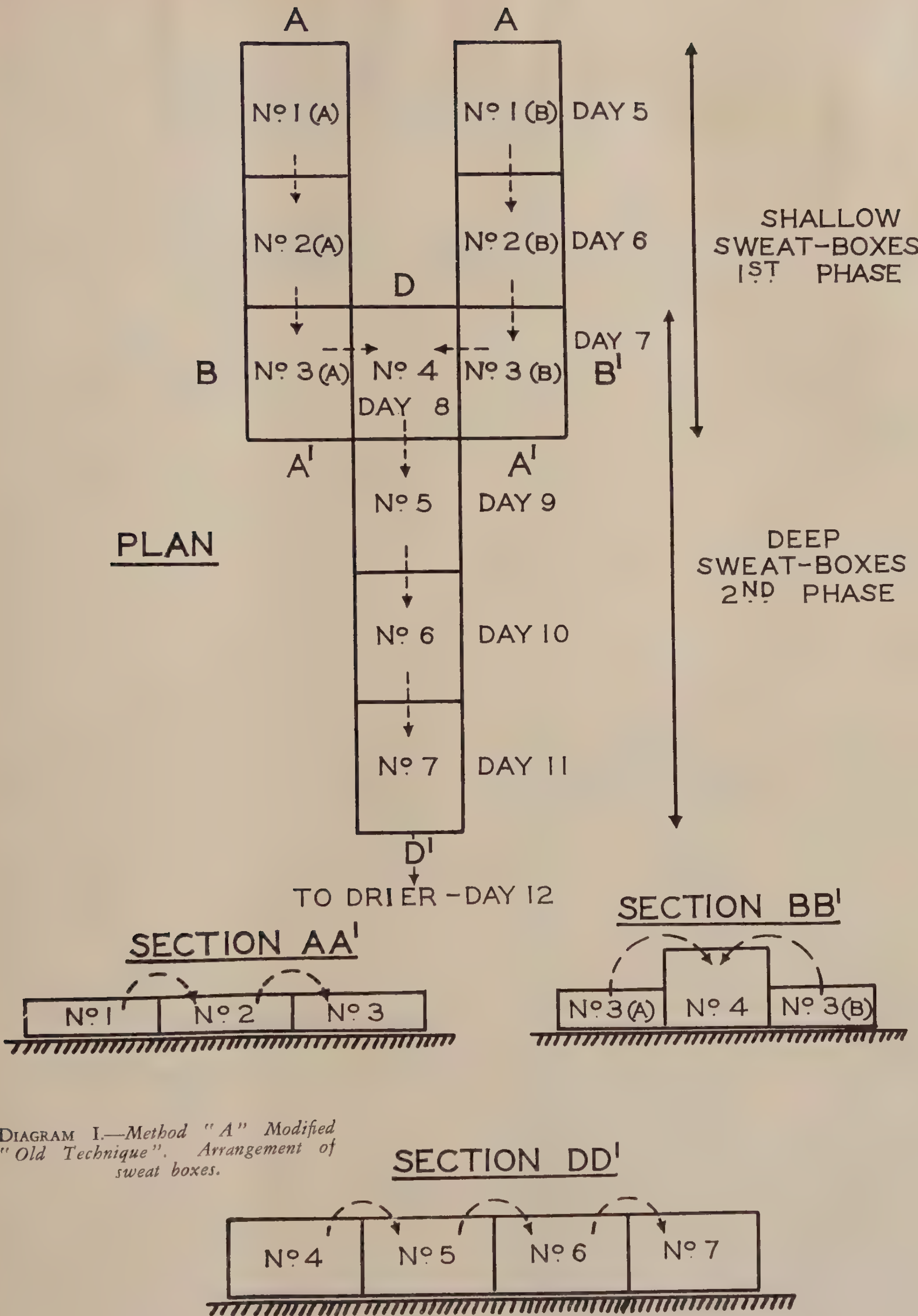


DIAGRAM I.—*Method "A" Modified "Old Technique". Arrangement of sweat boxes.*

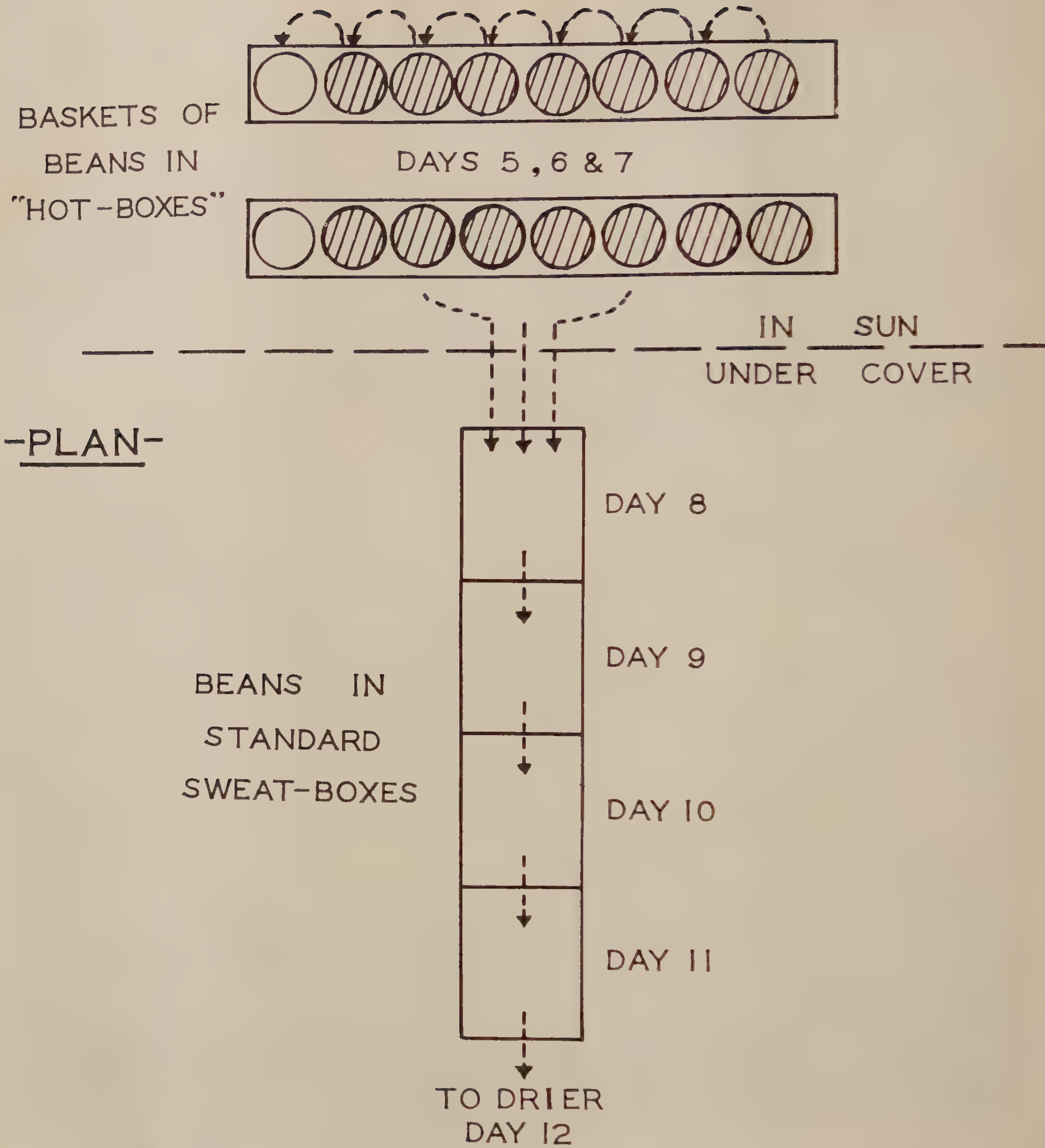


DIAGRAM II.—"*Basket/Box*" *fermentation. Arrangement of equipment.*

The sides of the shallow boxes can remain fixed. At this height there is no advantage in having the sides constructed so they can be dismantled. The sides of the shallow boxes can be made double-walled with some insulating material in the intervening space. This will conserve heat.

For the larger boxes in the deep phase of fermentation, the construction described by Henderson (1954) is recommended.

Provision for drainage of sweatings will be necessary only under the smaller sweat-boxes in the shallow phase. After this, there are no further sweatings, but provision must be made for draining away water used for washing the boxes. There MUST be a three-inch to four-inch air-space under all fermenting boxes. Half-inch holes should be drilled on a two-inch-square pattern in the bottoms of the shallow boxes in the first phase. Half-inch holes should be drilled on a six-inch-square pattern in the bottoms of the deep fermenting boxes in Phase 2.

Results

This method gives a sharper and more reliable temperature rise in the early stages of fermentation. Acidity develops more rapidly and reaches about the same level as in the "Old Technique". Beans are better fermented and flavour is improved. The effects of pulp variation are not as pronounced as in the "Old Technique". Slow ferments are not eliminated. The method gives a significant over-all improvement, but since a much more reliable method is available (Method "C"), it is not generally recommended.

METHOD "B"—"*Basket/Box Fermentation*"

This method has been developed in an attempt to find a simple, improved method suitable for use by central fermentaries in the Gazelle Peninsula, where management poses special problems, particularly for those in the cooler and wetter areas where difficulties with fermentation are marked.

The method involves fermentation in baskets placed in "hot-boxes" in the sun for three days, followed by conventional box fermentation for a further four days.

The beans are first placed in strongly-constructed cane baskets equipped with very strong and well-constructed carrying handles. The baskets are 20 inches high, have a top inside diameter of 24 inches and a bottom diameter of 16 inches. The bottom of the basket is not flat, but is slightly "coned" upwards in the centre. Each basket will hold about 200 lb. wet beans, or just under four cubic feet.

Baskets are placed in "hot-boxes" in batteries of eight, seven baskets being filled with beans and the eighth basket remaining empty to permit "turning". The "hot-box" is constructed of light timber and corrugated, galvanized iron. The outside of the box is painted black and the inside white. To accommodate eight baskets the hot-box should be 19 feet long and 2 feet 6 inches wide and the rims of the baskets should be flush with the top of the sides of the box when the lid is removed. A pole can then be run through the handles of the baskets and "turning" can be simply and quickly accomplished. A light lid consisting of a rectangular frame, covered with black-painted corrugated

PLATE 4.—*Baskets in fermentation box with lid removed. Note black-painted side to take advantage of solar heat.*

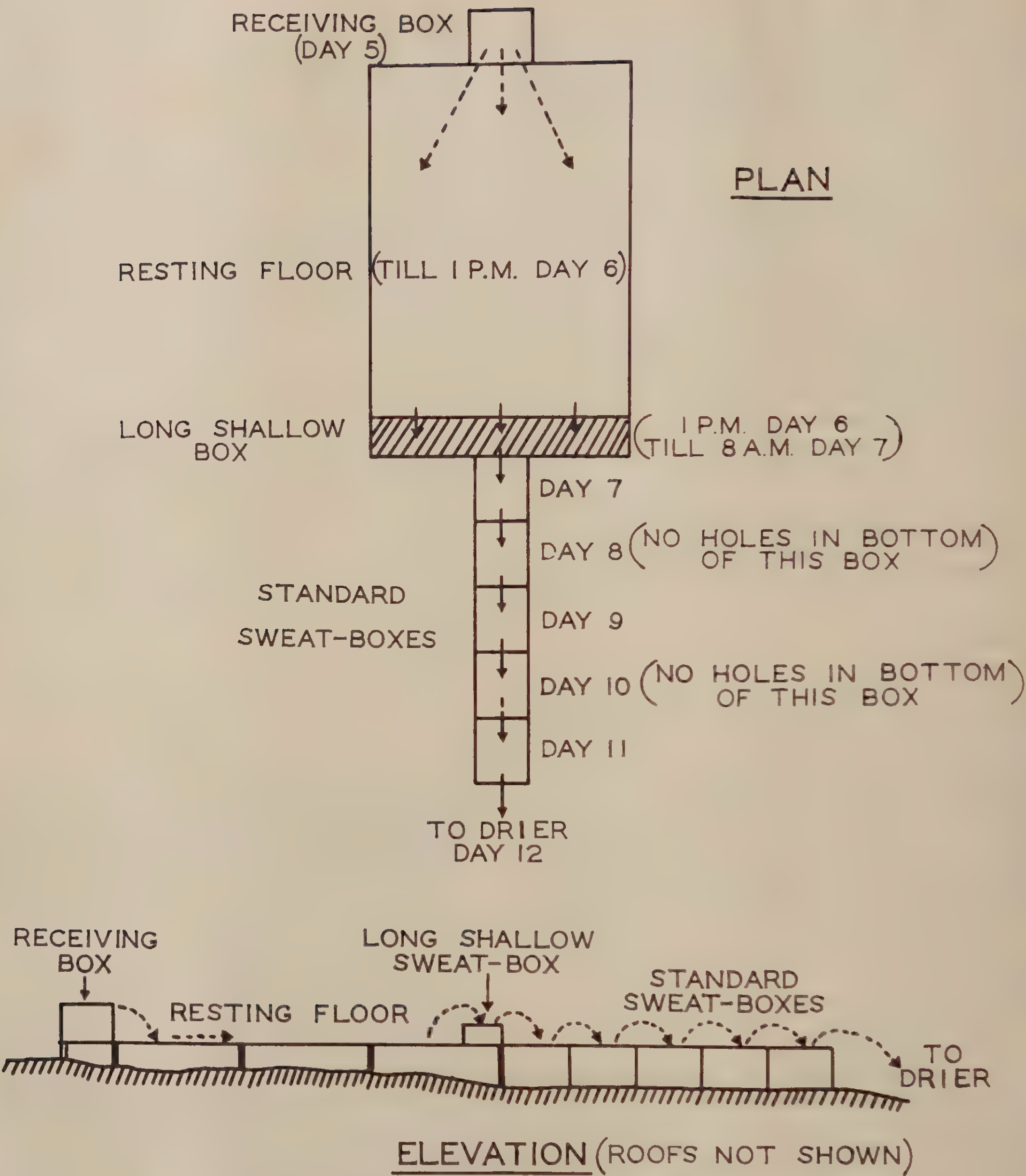


DIAGRAM III.—*Method "C"—"New Technique"*.

iron, covers the hot-box to give a reasonably close seal. The sides of the lid must be deep enough to keep the lid clear of the handles of the baskets, which stand about five inches above the rim. The baskets stand on 3-inch by 2-inch runners placed on the ground inside the hot-box.

On arrival at the fermentary, 14 baskets (two batteries) are filled with beans. These are turned every day for three days at 8 a.m. to 9 a.m. (on Days 6 and 7). After two and a half to three days, the contents of the 14 baskets are tipped into a conventional sweat-box where fermentation proceeds for a further four days with daily turning. Thus, fermentation is completed in six and a half to seven days.

Results

The method gives rapid temperature development (more rapid than Method "A") because of the reduced volume and heat assistance from the hot-box. The assistance from solar heat is advantageous but, basically, the method does not depend on this. Acidity is developed quickly, but reaches a lower level than in the "Old Technique". Flavour development is satisfactory, but not outstanding. The method is not affected greatly by pulp variation.

The additional handling is a disadvantage, but is largely offset by the greater reliability. The method is flexible, as the times at which the beans are turned can be varied, provided they are turned each day, without greatly affecting the results. The phase in the baskets may be prolonged for a day and the period in the sweat-boxes reduced by a day without any very apparent significant effect.

The method can be recommended only under special circumstances.

METHOD "C"—"*The New Technique*"

This method is recommended for general use. It departs from the "Old Technique" by introducing a short "resting phase" and by fermenting in a shallow layer for 19 to 20 hours subsequent to the "resting phase". This is followed by five days' fermentation in standard sweat-boxes 5 feet by 4 feet by 3 feet deep.

As the beans arrive at the fermentary, they are placed in a "receiving" or "draining" box. The beans remain in the receiving box until 6 a.m. the next day, regardless of the time they were received. During this period the "sweatings" drain away.

The beans are then spread out on the resting floor where they remain for six to seven hours with regular stirring. At 1 p.m. they are placed in a large and shallow fermenting box on the resting-room floor. The beans should be 12 to 15 inches deep. This box can conveniently be placed across the end of the "resting floor". The beans remain in this box for 19 to 20 hours (i.e., until 8 a.m. the next day) and are then transferred to standard fermenting boxes. Fermentation continues in these boxes for five days and the beans are turned at approximately 24-hourly intervals. Fermentation is completed in six and a half to six and three-quarter days. Fermentary lay-out for this method is given in Diagram 4.

Detailed Specifications :—

Day 1—Harvest.

Day 5—Break. Beans to receiving box, usually midday to 4 p.m. but not critical.

Receiving box to have a capacity of 60 cubic feet of wet beans, but should be loaded with 52 to 55 cubic feet only. Bottom of receiving box to be drilled in half-inch holes on a two-inch-square pattern.

Dimensions of receiving box not critical. The object of this phase is to get rid of excess sweatings as quickly as possible.

Day 6—Spread beans on resting floor at 6 a.m. to 7 a.m. (but not later) at the rate of one cubic foot of wet beans to 10 square feet of floor space. Do not spread the beans any thinner or any thicker. Spread evenly and stir by "walking" at 9 a.m. and 11 a.m. For a receiving box of 60-cubic-foot capacity, the resting floor should be 30 feet by 20 feet (for construction detail see "Design, Growth and Operation of Fermentary"). The objects of the resting phase are to stimulate the growth of yeasts and pulp maceration by these organisms, to evaporate excessive moisture and generally to get the bean into such a condition that temperature will jump sharply during subsequent fermentation. The resting phase will cause a reduction in acidity, but the level of acidity is maintained at a sufficiently high level to kill the bean and prevent putrefaction. Construct a box across the end of the resting floor (see Diagram No. 4) by standing two

walls 15 inches high on the floor. One wall should be on the very end of the resting floor and one 3 feet in from the end. This gives a long, shallow box 20 feet by 3 feet by 15 inches. (For further detail see "Design, Growth and Operation of Fermentary"). If required, the floor space in this box is available for beans during the resting phase. The bottom of this box MUST be drilled with half-inch holes on at least a four-inch-square pattern. These holes MUST be kept clear. Fill this box with beans off the resting floor at 1 p.m., gently firming the beans down to eliminate pockets of air. Thoroughly cover the beans with banana leaves and then bags. Good insulation is most essential. Double walls on the long, shallow box would be an advantage. The object of this phase is to create conditions which assist rapid temperature development and cause rapid and uniform killing of the beans.

Day 7—8 a.m. (or slightly later), transfer beans from long, shallow box to standard fermenting Box No. 1 (5 feet by 4 feet by 3 feet deep). Line all corners of this box with banana leaves and make sure that excessive pockets of air are eliminated as the box is filled. This box should have half-inch holes drilled in the bottom on a four-inch-square pattern. Cover the beans with banana leaves and bags. The object is to bring bean temperature to 45 to 50 degrees C. and to get the maximum possible destruction of the purple pigments (anthocyanins).

Day 8—8 a.m. (or slightly later). The No. 2 standard fermenting box should NOT be drilled with holes in the bottom. If it is, place a sheet of plywood without holes over the bottom of the box. Then turn the beans from Box No. 1 into Box No. 2. Cover with banana leaves and bags. The object during this day is to complete anthocyanin destruction and to prevent excessive aeration which could interfere with anthocyanin destruction.

Day 9—8 a.m. (approx.), turn the beans into Box No. 3. Line corners and sides of this box with banana leaves. This box MUST have holes drilled in the bottom on a six-inch-square pattern. The object on this day is to initiate oxidative changes in the bean.

Day 10—8 a.m. (approx.), turn the beans into Box No. 4. Line corners and sides of this box with banana leaves. This box should NOT have holes drilled in the bottom. If holes exist, cover the bottom of the box with a sheet of plywood

The object here is to carry oxidative changes to a stage further and inhibit any tendency to putrefaction by preventing reduction in acidity.

Day 11—8 a.m. (approx.), turn the beans into Box No. 5. Line corners and sides of this box with banana leaves. This box should have holes drilled in the bottom on a six-inch-square pattern. The object on this day is to carry oxidative changes further and reduce the level of acidity.

Day 12—8 a.m. (approx.), turn the beans out to dry. At this stage it is normal for a thin layer of beans from the very edges of the box to have a slightly "off" odour. If this layer is more than two inches thick (whatever the method of fermentation), the whole batch is likely to develop an "earthy" flavour, but it is impossible to prevent a slight tendency to putrefaction in a very thin layer of beans immediately adjacent to box walls.

Theoretical Basis

The method allows a period of viability of 32 to 36 hours. When the beans are placed in the long, shallow box following the short resting phase, temperature rises sharply to 42 to 46 degrees C. by the end of this phase 19 to 20 hours later. At the same time, cotyledon pH is brought almost to 4.5. The resting phase in combination with the initial shallow fermentation therefore quickly brings the beans to the conditions giving the maximum possible rate of anthocyanin destruction. The destruction continues during the next 48 hours during which oxygen uptake is held back. On the three remaining days of fermentation, oxygen uptake by the beans is encouraged but a safe level of acidity to prevent putrefaction is maintained. During this period, the beans will show an increasing amount of browning. Free liquid inside the bean will be muddy in appearance. When the beans are removed to the drier, the cotyledons should show pronounced browning just inside the bean skin and should have a bleached appearance at the centre. The more browning the better. Many beans will be completely brown.

Merits of Methods

(1) *Reliability.*

The method is not perfect but produces much more consistent quality than any other method yet devised. Chocolate-flavour development is greatly improved. The pattern of fermentation may show slight alteration as a result of pulp variation, but this is considerably less than with any other method. Method " C " does not therefore completely remove the causes of " dead ferments " but goes a long way towards it. At times when the " Old Technique " would produce beans of very low quality, the new technique would produce beans which would be acceptable to manufacturers. The method does not eliminate " underfermented " beans altogether, nor should it. The presence of 10 to 15 per cent. underfermented or " partly fermented " beans is the manufacturer's insurance against loss of flavour by over-oxidation. Badly underfermented beans are rare in Method " C ". Using this method, there is a higher tolerance of underfermented beans. Even if the percentage rises above 20 per cent. there is very little loss of chocolate flavour. In this, Method " C " differs a good deal from other methods.

(2) *Costs.*

The installation of resting floors and the labour involved in spreading and regathering beans from the resting floor, might be expected greatly to increase processing costs. This is not so. Method " C " reduces fermentation time as compared with the " Old Technique " and labour costs for the two methods are almost the same.

The cost of installing resting floors is partly offset by the reduced number of fermenting boxes required and by the corresponding reduction in the size of the fermentary building. The saving of one or two days in fermentation time means that there is a potential increase in fermentary output of 12 to 25 per cent. The cost of the resting floors is fully justified by this and by the improvement in quality.

(3) *Flexibility.*

Generally speaking, it is recommended that instructions outlined above be adhered to. Under certain circumstances the method can be varied slightly to produce any desired modification in the pattern of fermentation. On a very wet day when evaporation rate is low, the resting phase can be extended by one to two hours with advantage. Other steps in processing take place on schedule.

If the beans should occasionally remain very acid (and such an occurrence will be rare), this can be overcome by prolonging the resting phase for one to two hours. If the level of acidity falls too low and beans develop a marked " off " odour by the end of fermentation, in future ferments reduce the duration of the resting phase by one to two hours and omit the stirring during the resting phase. In the " off-crop " season when acid development is usually less, the same effect can be produced, without detriment to quality, by reducing fermentation time by one day.

As a general rule, the modifications noted here are unnecessary and growers are advised not to alter the method unless absolutely compelled to do so. Within this limitation, the method can be varied to produce any desired alteration in the level of acidity. Revert to standard practice as soon as conditions return to normal.

FERMENTING SMALL QUANTITIES

Methods used successfully in West Africa are inapplicable in New Guinea where the fermentation of small quantities of Trinitario beans is difficult. It is virtually impossible to turn out a consistently good product.

The problem arises when a plantation first starts to bear and for a short period during the " off-crop " season when the plantation is young. Wherever possible, it is recommended that small quantities of pods be disposed of to a neighbour who is producing on a reasonable scale or that neighbours pool their first harvests to give a satisfactory volume of beans.

Where this is not possible, the following method will give reasonable results :—

1st Day—Harvest.

5th Day—Break. Place the beans in one or more baskets as described for Method " B ". Place the baskets in a " hot-box " in the sun as for Method " B ", but with appropriate reduction in the length of the hot-box. Try to have this done by 9 a.m.

6th Day—Turn into a similar empty basket, 8 a.m. to 9 a.m.

7th Day—Turn into an empty basket, 8 a.m. to 9 a.m.

8th Day—Turn into an empty basket, 8 a.m. to 9 a.m. At 4 p.m., turn again into a basket lined completely with banana leaves (top, sides and bottom). Press the beans into the basket firmly.

9th Day—Turn into an empty basket at 8 a.m. to 9 a.m. At 4 p.m., turn again into a similar basket lined completely with banana leaves. Firm the beans in this basket.

10th Day—Turn into an empty basket at 8 a.m. to 9 a.m. At 4 p.m., turn again into a similar basket lined completely with banana leaves (top, sides and bottom). Firm the beans in this basket.

11th Day—Turn out on to trays and sun-dry slowly with continual stirring over a period of seven to ten days. The drying rate should be kept slow during the first three days, then wet the beans, rub on hessian or sacking and complete the drying slowly.

The method cannot be guaranteed, but the product is usually fair. Quantities as small as three to four cubic feet of wet beans can be fermented in this way. As more beans become available simply use more baskets. When four or five baskets can be filled, follow Method "B" until further increase in production permits the use of Method "C".

FURTHER DEVELOPMENTS

Work is continuing at Keravat to obtain still better control of fermentation. This work is based on Method "C". Small modifications and refinements may be recommended later on, but the basic fermentary equipment, layout and design will remain unaltered. It is most unlikely that major alterations will become necessary.

GENERAL NOTES

Adjustment of Bean Depth in Boxes

When breaking commences, it is difficult to judge the quantity of wet beans which will be produced, but generally speaking the planter will know whether one, two or three boxes will be required. Care should be taken to ensure that boxes are filled evenly to avoid having a small fraction of a box left over. It is far better to have two boxes just over half full than one full box and one with a very small quantity.

For Method "C", if a box is only three-quarters or half full, spread the beans over only a corresponding proportion of the resting floor. Insert a false end wall in the long, shallow fermenting box so that beans are maintained at a depth of 12 inches to 15 inches. Steps to increase the depth of beans in the large, standard fermenting boxes will be unnecessary unless the depth falls below 18 inches. In such cases, insert a false end into these boxes as well so that a minimum depth of 18 inches is obtained. Such batches show a greater tendency to putrefaction by the end of fermentation. Accordingly, take steps to restrict aeration on the last day of fermentation. This can be accomplished by lining the bottom, sides and tops of the fermenting boxes with banana leaves. The aim is to reduce air penetration, not to eliminate it altogether. Alternatively, reduce fermentation time by one day.

"Turning"

The turning of beans from box to box should be accomplished without unreasonable delay. Beans should be well-aerated during the "turn". Large lumps and masses of beans should be broken up. To obtain uniformity, beans which were on top of the box should go on to the bottom of the next box. Thus, beans should be removed in layers rather than from one end of the box and then the other. As the beans are turned, they should be gently firmed down so that pockets of air are removed.

Cleaning

Boxes should be sluiced down and roughly cleaned with a scrubbing brush after every few batches. This is a good Saturday morning job. It is not necessary to use any fungicide.

Every few months (during the off-crop season), the fermenting boxes should be completely dismantled, scrubbed and sunned. There is no necessity for the use of fungicides, bactericides, etc., unless the boxes have become quite foul.

Use of Banana Leaves and Bags

Use of banana leaves has been widely recommended above. The leaves should not be used as a cover over the bottom of fermenting boxes unless this is explicitly advised.

Planters should establish an area of bananas convenient to the fermentary so that a good supply of leaves is assured.

At all stages of fermentation and irrespective of the method used, the beans in a fermenting

box should be covered with one or two layers of fresh, green banana leaves and then with at least two layers of bags. This conserves heat.

METHODS OF DRYING

Drying During "Flush-Crop"

For Trinitario beans, slow drying is essential. The best compromise between reduced drying costs, the minimum capitalization and the production of high-quality beans consists of hot-air drying on a platform-type drier for 24 hours, followed by an interruption of 48 hours in drying, followed by completion of drying in a further 24 hours in a rotary drier. This means that drying is completed in not less than four days, but drying equipment is occupied for only two days. Any one drier is occupied for only 24 hours. There is no bottleneck in processing at the drying stage and fermenting equipment can therefore be used to its maximum capacity.

This splitting of the drying between two drying units means that if they balance each other there is very little wastage of drying capacity due to shrinkage and loss of weight during drying. While both driers are occupied they are working at virtually full capacity. This is a more efficient arrangement than completing the drying of a batch of beans on the one drying unit where the unit is working at only half capacity by the end of drying, owing to shrinkage in volume and loss of weight. This is particularly marked with complete "rotary" drying. The capacity of such a drier is quite inflexible to begin with. If drying is spread out over four days, not only does this create a bottleneck in the flow of beans through the fermentary, but the use of the machine is inefficient. It is working at only half capacity by the end of drying.

With the combination of platform/hot-air drying and rotary drying, the loss of weight and shrinkage obtained on the platform drier means that the rotary drier need have a smaller capacity than if it were used alone. To put the proposition another way, if a rotary drier of given capacity is fully charged with half-dry beans (taken from a platform drier of correspondingly greater capacity) then its output in terms of dry beans from a single charge will be 66 per cent. higher than would be the case if it alone were used to dry wet fermented beans.

The "split-drying" increases the efficiency of the two drying units used. Drying should not be accomplished in less than four days, but with the arrangement suggested the total amount of drying equipment required is reduced by half and the quality of the product is not greatly affected.

DETAILS OF PROCEDURE

1st Phase—On Platform/Hot-Air Drier

Place the wet fermented beans on the platform/hot-air drier. This unit should be equipped with a sliding roof so that the sun's heat can be used when available. Spread the beans uniformly. This should be completed by no later that 8 a.m. Use the sun throughout daylight hours if available. Continually stir the beans on the drier. No hard and fast recommendations regarding artificial heat can be made. This will depend on the intensity of solar heat and the thickness to which beans are spread. Artificial heat is required throughout the night, the intensity depending on the moisture loss during daylight hours and the rate of airflow. Beans should be stirred at intervals during the night to ensure that drying is uniform.

NOTE.—The object of this phase is to dehydrate the beans sufficiently to ensure that they will not putrefy or develop an "off" odour during the period of interruption to drying. To achieve this, fairly rapid drying is required over the 24-hour period. Excessive temperature must be avoided. The temperature of the beans themselves should never exceed 50 degrees C. (120 degrees F.). During this first 24 hours' drying, the cooling effect of rapid evaporation means that an air temperature of 160 degrees F. is safe. With a thick layer of beans, excessively high temperature and low rate of air-flow, the beans are likely to be "stewed" and will develop an obnoxious foreign flavour. If prolonged, this treatment will produce the objectionable "burnt" flavour.

The appropriate stage to interrupt drying is largely a matter of experience, but the following points should be noted :—

(1) At the end of the first 24 hours' drying, the beans should be dry to the touch externally.

(2) On cutting at this stage, there should be just a little free moisture within the beans. The cotyledon should be of a rubbery consistency. If the bean contains too much free moisture, this will come to the surface during the period of interruption and will cause putrefaction.

(3) If, at the end of 24 hours, the beans are not quite dry enough, extend drying until they are. Reduce the duration of the interrupted period accordingly. If the beans are sufficiently dry before the 24 hours has expired, merely stop drying. Then go ahead with the interrupted phase on schedule.

(4) If beans are over-dried during the first 24 hours, the benefit of the interrupted phase will be almost entirely lost and there will be a marked drop in quality.

2nd Phase—Interruption

Place two lightly but strongly constructed boxes so that they can be loaded conveniently from the platform drier. Each box must be big enough to accommodate a full charge from the platform drier. The boxes must be under cover. The dimensions of the boxes are not critical, but should be such that a depth of at least 18 inches of beans is obtained. It is better if the beans are warm or hot when placed in these boxes. The beans remain in these "holding" boxes for 48 hours. Do not prolong this period unless the pre-drying has been carried too far.

The holding boxes can be conveniently sited at the end of the platform drier or near the rotary drier. The best arrangement will depend on the particular fermentary design. If the processing units are arranged on a slope, labour is saved when the loading platform above the rotary drier is on the same level as or just below that of the floor of the platform drier. In this case, the holding boxes can be placed on the loading platform over the rotary drier.

In the flush crop, the normal sequence of events will be—

(1) Empty one holding box (Box A) after 48 hours and charge the rotary drier.

(2) The other holding box (Box B) will have been filled 24 hours before. These beans remain as they are.

(3) Fill the empty holding box (Box A) with a full charge off the platform drier and recharge this drier.

(4) On the following day, discharge the rotary drier and recharge from Box B. Fill Box B off the platform drier and recharge this drier. This can go on until crop pressure eases off.

As an alternative, beans can be bagged off the platform drier and held for 48 hours and then loaded into the rotary drier. Only clean, dry bags should be used for this purpose. Store the bags in a convenient position under good cover for the 48-hour period.

NOTE.—The object of the interruption to drying is to allow oxygen uptake by the beans. This causes them to go brown. It will have taken place to some extent during fermentation and during the first 24 hours' drying, but if drying is completed rapidly the enzyme responsible for the oxidative changes will be inactivated, and shrunken, "under-fermented" beans will result. Happily, the beans which most require further oxygen uptake tend to lose moisture at a slower rate than those in which oxygen uptake is already sufficient.

At the end of the interrupted phase, the beans will have softened to a rubbery consistency. The cotyledons should have become open-textured and brown, but perhaps with a residual purple or whitish cast. Externally, the beans will appear to be moister than when first placed in the holding box. A light speckling of surface mould or a whitish blush on the beans' skins at this stage is not detrimental.

If the initial drying has been insufficient the beans will be quite mouldy and the odour will be mouldy, earthy or foul. This is most detrimental to flavour. It is quite easily avoided by giving sufficient pre-drying. At the end of the interrupted phase the beans should have a strong "cocoa" odour with a slight acid background. This acid background is desirable.

In the initial platform drying, the moisture content of the beans should be reduced to 20 per cent.

3rd Phase—Rotary Drying

Charge the rotary drier with equal loading of all compartments. Load two opposite compartments first and then the other two. The machine will remain balanced if the loading of opposite compartments is equal. Wet the beans in the rotary drier using built-in watering facilities or a hose through the doors. A considerable quantity of water is required. In a six foot by six foot rotary drier, 20 to 25 gallons of water are required for a full charge. In a seven foot by six foot, 30 to 35 gallons are required.

Fire the drier and start the drum. An initial air inlet temperature rising to 160 degrees F. is adequate. Air temperatures of 180 degrees F. can be tolerated for a few hours at the beginning of this phase only. If prolonged, the beans will develop a roasted or burnt odour and flavour. The initial drum speed should be two r.p.m. and this should be reduced to one r.p.m.

after four to five hours' drying. This speed can be maintained for 20 hours or slightly longer if necessary. If the beans have not been wetted in the drum, the advantages of rotary drying will be largely lost and there will be severe breakage unless the speed is reduced to $\frac{1}{4}$ r.p.m. or less.

After eight to 12 hours from the time of loading, reduce the air temperature to 140 degrees F. If the rate of airflow is such that this causes overheating of the beans, reduce the air temperature to 120 degrees F. Complete the final drying in 24 hours.

If the rotary drier is of the recirculating type (i.e., if the drum is enclosed in a box and air recirculated back through the heat-exchanger), wet the beans as above. Drum revolutions also remain the same. However, as bean temperature follows air temperature much more closely, air temperatures must be watched closely. The greater the air velocity, the more closely will bean temperature approach the temperature of the recirculating air. Where the rate of recirculation is very rapid, the temperature of the recirculating air should not exceed 130 degrees F. When the machine starts to operate, work with full recirculation until bean temperature reaches 120 to 125 degrees F. This should be achieved within an hour or two. Then open ventilators and dry at progressively decreasing humidity. Complete the drying in 24 hours. Better methods of handling driers of the recirculating type may be evolved as further information is obtained.

With most types of rotary driers, it is necessary to stop the drum two to three hours after the beans have been wetted and dislodge any beans sticking on to the perforated coreplate, against obstructions and in corners. With the method recommended, it is necessary to do this only once. After this the beans flow freely and do not stick.

NOTE.—The objects of the rotary drying phase are :—

(1) To complete the curing of the beans.

(2) To dehydrate the beans to 6 per cent. moisture.

(3) To reduce skin percentage.

(4) To impart an attractive appearance and polish to the beans.

The desired reduction in shell percentage cannot be obtained unless the beans are wetted down as described above. If the amount of water used is reduced the beans will become polished and the reduction in skin percentage will be less. It should be well noted here, however, that the addition of too much water will result in excessive clogging. Even when the optimum amount of water is added (i.e., just enough to make the pulp quite soft) clogging will result if the perforations in the outer skin of the drum are not at least 5/16 inch in diameter. With the recommended treatment, skin percentage can be reduced from more than 16 per cent. to 13 or 14 per cent.

Why wet the beans when the object is to dry ? The wetting permits reduction in skin percentage, reduces acidity, tends to "plump" the beans, prevents shattering and promotes a very even polish. Only the pulp is affected by the wetting. Moisture is not taken up through the bean skin. The effects of wetting last only a few hours. The "shipping" qualities of the beans remain unaffected by the treatment outlined above.

Softened pulp will gradually be extruded through the perforations in the drum during drying, but the holes will still permit the free flow of air. The grower should take no notice of this. It should not be touched until it is bone dry. It can then be easily scraped off in a few minutes as the drum revolves, leaving the perforations clear. It seems that mucilage or pulp is not extruded if the perforations in the skin of the drum are of the "drawn" type.

On the general question of "clogging", those rotary driers in which there are no internal obstructions are almost free of this problem. However, any internal obstructions become a focus around which wet beans will gradually build up. In the six foot by six foot rotary drier at Keravat, all baffles in each compartment were removed. In addition to causing clogging, these baffles had the effect of crashing the beans about inside the drum, leading to shattering. Removal of the baffles did not adversely affect the machine in any way, nor has it affected the rate or uniformity of drying. Similarly the original perforations in the outer skin of the drum have been enlarged to a diameter of 3/8 inch. This has tended to prevent clogging and restriction of airflow and has also had no adverse effects. Enlargement of all perforations to 3/8 inch carries no risks with a six foot by six foot rotary drier, but there may be a risk of over-weakening in the case of a seven foot by six foot drier where the effect on the overall architecture is more pronounced. The manufacturer's advice should be sought on this point.

If the drum of the rotary drier is not completely filled so that there is an air-space in each compartment, the movement of the beans within

the compartment reduces the tendency to clog. To accommodate a full charge off the platform drier, the choice may be between using a six foot by six foot rotary drier completely filled, or a seven foot by six foot drier, leaving a larger air-space. Under these circumstances, better results will be obtained with the seven foot by six foot drier. With a 40 foot by 20 foot platform/hot-air drier, the out-turn of half-dry beans can be accommodated in a six foot by six foot rotary drier, but the rate of drying and reduction in skin percentage will usually be faster in a seven foot by six foot rotary drier.

Drying During "Off-Crop" Season

When production eases off, the whole pace of drying can be reduced. This will be reflected in slightly better quality beans. As soon as the crop-pressure falls, the initial drying on the platform drier can be spread over 48 hours instead of being hurried along in 24 hours. This does not mean continuous operation of the drier with artificial heat for this period. Heat can be applied when necessary in short bursts. Gentle heat is required on the first night up to 10 p.m. to 11 p.m., after which the drier can be shut down. Use the sun or artificial heat the next day until the beans are surface dry. Then shut down the unit and heap the beans on the platform under cover.

On the third morning, charge the rotary drier and apply steady heat for 36 to 40 hours after first wetting the beans in the drum. Shut down over the second night. Then complete the drying during the next 24 hours.

With this method, the holding boxes are by-passed. Their use during the flush crop enables the grower to double the output of his drying equipment, but this is not necessary in the off-crop season.

GROWING UP WITH COCOA DRIERS.

The arrangement of driers described above is the final arrangement. When it can no longer cope with production, the arrangement can be duplicated either gradually or *in toto*, depending on anticipated increase in production. It is also possible to build up the original installation according to needs.

When the plantation first begins to bear, a start can be made with a 40 foot by 20 foot sliding roof sun-drier. It will accommodate the equivalent of 15 cwt. of dry beans and will handle about 15 tons of dry beans per annum.

As production expands, the sun drier can be converted to a "forced-hot-air" platform drier, provided this was allowed for in its original design. Its capacity per full charge will then be equivalent to a ton and a half of dry beans and its annual output will be about 45 tons.

When this production is outgrown, a rotary drier and holding boxes as described above can be installed. This arrangement is then theoretically capable of handling (disregarding management problems for the moment) a crop of 190 tons per annum if the equivalent of a ton and a half of dry beans is coming forward for drying five days in every week during the flush crop (if 8,500 lb.—three boxes each of 52 cubic feet—of wet beans reach the fermentary on each of the five days in each week). Management problems will reduce this figure, but the potential is there.

With the final arrangement, drying equipment can be fully exploited only with daily "breaking", but various factors may prevent this. As the frequency of breaking diminishes, so the capitalization required in driers increases. Fermentary capacity is discussed more fully at a later stage. It is more relevant at this point to describe the best methods of utilizing the various types of driers at different stages of growth before the final arrangement is achieved.

Use of Sun Driers

Get the fermented beans on to the sun-drier as early as possible in the morning. Spread the beans evenly and stir by "walking" every hour or so throughout the day. Do NOT heap the beans on the first night. On the second day, stir as before and pull the roof over the beans for a few hours in the middle of the day. Heap the beans under the roof on the second night. On the third day, spread the beans in the sun until 10 a.m. to 11 a.m., then heap, wet and "dance". "Dancing" imparts an attractive polish to the beans and aids the curing process. Use sufficient water just to wet and soften the pulp on all beans. For efficient "dancing" at least six labourers are required for about half an hour. Four labourers should keep pushing the beans into a heap while the other two vigorously jog up and down with their feet. Do not allow the heap to become flattened or beans will be damaged and avoid getting excess water over the drying floor. Spread the beans out in the

sun again. Heap the beans under the roof on the third night only if they are surface dry and not likely to mould. Complete the drying gradually in the next four days. Rate of drying can be reduced by increasing the thickness of beans on the floor.

The above procedure applies during fine, sunny weather. Adjust the process according to weather conditions. Do not heap the beans under the roof on the second night if the rate of drying has been slow and the beans are still "tacky" to the touch. Do not "dance" on the third day, but defer until the fourth or fifth day if the rate of drying has been very slow. The beans should be at the "soft leathery" stage when "danced". Do not "dance" on a day which is overcast or if rain threatens. At all points, be guided by the odour of the beans. If there is any suggestion of an earthy, foul or mouldy odour, do everything possible to increase the rate of drying. While the "acetic" odour remains, a slow rate of drying is advisable. Do not overload the sun-drier as this will inevitably lead to putrefaction within the first two or three days.

High-quality beans can be produced by sun-drying until prolonged bad weather intervenes. It then becomes impossible. Good sun-drying is a fine art and constant supervision is required.

Use of the Platform/Hot-air Drier

The point is reached where the grower has a sliding roof/platform/hot-air drier, but no rotary drier. In the "off-crop" season, it may not be necessary to use artificial heat except during bad weather. The unit is used primarily as a sun-drier. Artificial heat can be given in short bursts when required.

During the "flush-crop", drying should not be completed in less than four days. If a full charge of beans remains on the drier for four days, this means that pods can be broken only once every four days. Using the drier this way means that a production of 45 tons per annum can be handled, provided fermentary equipment is such that it can be fully charged. It would be possible to double this by installing holding boxes so that a given charge occupies the drier for only two days. The method would be as described above, except that the final day's drying would take place on the platform drier instead of the rotary drier. This procedure would make it possible to "break" on three successive days. There would be no more breaking during the next three days after which the process could be repeated. The disadvantage of this procedure lies in the extra handling required.

It is inadvisable to have two different batches of beans at different moisture contents on the drier at any one time. Treatment required for one batch usually does not suit the other. If one batch which is half-dry is pushed to one end of the drier and a fresh charge placed on the vacant space, the fresh charge will dictate the necessity for fairly hard drying. While this is being done, it is impossible to stir the deeply spread, half-dry beans. The result will be scorching or at least "over-drying" of portion of these beans while others will remain moist. It is impossible to get an even rate of drying and the object of getting greater output will be defeated.

In any form of hot-air drier, it is most important to keep the beans moving. Do not allow them to stick to the floor. If this happens, a fragment of shell is torn off when the beans are gathered up. Such beans are then subject to insect infestation and internal mould. If the drier has hot or cold spots, reverse the position of the beans regularly.

Excessive temperatures must be avoided at all costs. Where it is desired to increase the rate of drying beyond that given at 160 degrees F., increase the airflow (if this is possible) NOT the temperature. Hard and fast recommendations regarding air temperature cannot be made. The tolerance depends on the rate of airflow and the moisture-content of the beans. High air temperatures at the beginning of drying are less dangerous than later. When the beans become half-dry, they tend to heat up and high air temperatures will cause scorching or roasting. As a rough guide, bean temperature should never rise to the point where a handful of beans feels uncomfortably hot. Bean temperature should not exceed 50 degrees C. (122 degrees F.).

Use of Rotary Driers

(When used alone or in conjunction with sun-driers. For use in conjunction with hot-air driers, see above.)

A few growers have equipped themselves with rotary driers for use alone or in conjunction

PLATE 5.—*Sliding roof platform driers at Keravat.*

with sun-driers. In the latter case, to complete drying in not less than four days, there are three possible alternatives :—

(*a*) One day's sun-drying—no re-wetting plus three days' rotary drying.

(*b*) Two days' sun-drying—light re-wetting plus two days' rotary drying.

(*c*) Three days' sun-drying—moderate re-wetting plus one day's rotary drying.

All these methods will give equally good results. Two days' sun-drying plus two days' rotary drying will give the greatest output since this will permit "breaking" every second day. In rough terms, it will require two standard sun-driers (dry bean capacity, 15 cwt.) to balance one six foot by six foot rotary drier, or three standard sun-driers to balance a seven foot by six foot rotary drier. For this arrangement, use the rotary driers as described above.

There is no objection from a quality point of view to complete rotary drying provided this is accomplished in not less than four days. Wet fermented beans produced by the "Old Technique" or Methods "A" or "B" will usually cause serious clogging of a rotary drier. Such beans should get some pre-drying before being placed in a rotary drier. With Method "C", beans can be placed direct in the rotary drier. Even with this method, however, it is necessary to stop the drum once after a few hours' drying and dislodge from corners and crevices any beans which are not moving freely within the drum. At no stage are the beans wetted.

If the beans are completely rotary dried (Method "C" only), the machine is normally loaded at 8 a.m. to 9 a.m. It should be run continuously until 10 p.m. to 11 p.m. on the following day and then shut down. It need run for only 10 to 12 hours on each of the remaining two days to complete curing and drying.

No matter how a rotary drier is used, it is an advantage to turn the drum at two r.p.m. for the first few hours of drying. After this, drum speed depends on how long the beans are to remain in the drum :—

For four days' rotary drying—Drum speed, $\frac{1}{4}$ r.p.m.

For three days' rotary drying—Drum speed, $\frac{1}{2}$ r.p.m.

For two days' rotary drying—Drum speed, $\frac{3}{4}$ r.p.m.

For one day's rotary drying—Drum speed, one r.p.m.

NOTE.—This assumes no internal baffles; if there are any, halve the speeds. If perforations in the skin of the drum are of the "drawn" type, the speeds can be doubled. This variation is necessary to achieve the desired reduction in skin percentage without causing damage to the bean skins.

Complete rotary drying is uneconomical. If it extends over a period of four days, an expensive machine is tied down for this period and

during the last two days of drying it is working at only half capacity owing to shrinkage in volume and loss of weight. Complete rotary drying is not recommended.

DRIER CONSTRUCTION AND DESIGN

Sun-Driers

(1) The drier should be low for ease of loading and unloading.

(2) It should have adequate ventilation below the drying floor.

(3) The floor should be firm and substantial so that several labourers can work on it. For this reason, a sliding roof over a fixed floor is preferable to sliding trays under a fixed roof.

(4) The sliding roof should be easily managed. Ridgecapping should be "jacked" a few inches to prevent condensation on the under-surface of the roof during the night. The under-surface of the roof should be painted with acid-resisting paint.

(5) There should be sufficient clearance between the roof and the floor to enable labourers to work under the roof in wet weather.

(6) All ties, joists and end-walls of the roof should be high enough to clear beans heaped on the floor to a depth of about a foot.

(7) The building must be structurally sound.

(8) Experience at Keravat indicates that properly treated galvanized iron roof lasts better than aluminium. The evident advantages of the latter are generally outweighed by its lack of durability.

Platform/Hot-air Driers

I. *Kiln Type*

Satisfactory methods of operating this type of drier have been fully described by Henderson (1954). If they are used carefully and judiciously, high-quality beans can be produced, but as a type kiln driers are not recommended. The types in common use throughout the Territory are difficult to control, costly to operate and lend themselves too readily to abuse. Virtually all the "hammy" beans and 90 per cent. of the "burnt" beans now being produced come from this type of drier. These objections can be overcome if the drier is properly designed and properly managed. The main points to remember are :—

(1) A kiln-type drier has a fixed maximum capacity. No attempt should be made to increase this capacity by raising the temperature above normal limits. As the rise in temperature cannot be balanced by greatly increased airflow, the beans will "stew" and burn.

(2) Even with careful management, "burnt" beans will inevitably be produced if the kiln pipes are too close to the drying floor or if the chamber under the drying floor is not suitably baffled to break up convection currents of very hot air. Kiln pipes should not at any point be closer to the beans than five feet.

(3) The slightest smoke-leak in the kiln pipes will cause the development of a "hammy" flavour in the beans.

(4) Having regard to the minimum construction requirements, the close supervision required, the fuel consumption and the difficulty of control, kiln-type driers are just as costly as the more efficient types of driers, if not more so. Kiln-type driers are the least satisfactory of all in regard to heating efficiency.

II. *Forced-air Type*

With the much more rapid and controllable rate of airflow given by this type of drier, a sufficiently high rate of drying can be obtained without using high temperatures. This obviates the risk of "burning". Furthermore, there is very little risk of "hammy" flavours being developed. As long as the heat-exchanger is kept in good condition, there is no risk at all.

Important points in design are :—

(1) Structural soundness and mechanical simplicity.

(2) Efficient heating of air within the temperature range required and within the range of variability of air velocity.

(3) The drier must be so designed that the rate of drying can be controlled. To suit the system recommended above, the maximum requirement is that the unit must be able to reduce the moisture content of 7,000 lb. of wet fermented beans to 20 per cent. in 24 hours without any assistance from the sun. The ability to vary temperature (and also airflow if possible) is necessary when the unit is working below its maximum capacity.

(4) The drier should be so designed that loading and unloading are rapid and easy. This will be so if the floor is low and there is a sliding roof.

(5) There should be no hot or cold spots on the floor. The drying rate of beans spread over the floor must be uniform.

(6) A sliding roof is essential in reducing operating costs and in providing a certain margin of safety in the rate of drying and in the event of mechanical failure. The sliding roof should travel far enough off the drying platform to ensure that its shadow never falls on the drying floor.

Rotary Driers

The following points are important :—

(1) To suit the drying system described above, the rotary drier must have the capacity to reduce the moisture content of 4,000 lb. beans at 20 per cent. moisture to six per cent. moisture in 24 hours.

(2) Structural soundness, durability and "finish" on the machine are even more important than with any other type of drier.

(3) The machine must resist serious clogging. These requirements have been noted above.

(4) Variable drum speed is a great advantage, but not absolutely essential, provided the grower gets the appropriate speed to suit his method of drying and provided he does not depart from this. However, in addition to this one main operating speed, it is an advantage to have also a speed of two r.p.m. There will be times during the off-crop season when the rotary drier is used at half capacity or less. A small charge receives correspondingly greater wear during drying. Damage can be prevented if a slow drum speed of ¼ r.p.m. or less is available. Without having variable speed, much the same effect can be obtained by running the drum intermittently. This is necessarily wasteful of fuel.

(5) There should be no significant temperature gradient from one end of the drum to the other. Uneven drying in different parts of the drum is a serious defect.

(6) A recirculation system offers certain advantages. The humidity control makes it possible to stimulate the final "curing" and "plump" the beans. The system gives a substantial fuel economy. Actual figures should become available in the near future. Further experience is required before it can be determined whether conventional materials involved in the recirculation system will be affected by corrosion from acetic acid vapour. However, with the drying system recommended in Method "C", acid vapour has largely disappeared by the time the beans are placed in the rotary drier. After rewetting, it may be desirable to run the machine for a short time without recirculation to drive off remaining acid. Parts which are exposed to acid vapour should be treated with some acid-resisting compound.

Note on Oil Firing

In producing heated air, the two factors to be considered are efficiency and economy. With the control given by well-designed fuel injectors, there is a decided gain in efficiency from oil-firing as compared with the more clumsy stoking with solid fuel. There is less fuel wastage where the amount of fuel injected can be controlled within precise limits to suit the capacity of the particular heat-exchanger. Air temperature can be controlled with a high degree of precision.

However, the choice of oil-firing or solid fuel will be determined almost wholly by comparative costs and the level of production. Frequently, but not invariably, availability and low cost are on the side of solid fuel. Equally frequently, the cost of solid fuel is underestimated. On the side of oil-firing is reliability, control, reduced supervision and labour costs and prolonged life of the heat-exchanger. The margin between the two alternatives often depends on whether fuel-oil can be delivered in bulk or not.

For the smaller and the intermediate-sized producer, oil-firing is strongly recommended where costs approach equivalence. The large producer (say 100 to 120 tons per annum or more), who is in no position to make sudden alternative arrangements for the drying of large quantities of beans in the event of fuel shortage, has almost no alternative. He must oil-fire or face either increased costs or chaos unless he has exceptionally favourable supplies of solid fuel.

It requires the burning of a ton and a quarter to a ton and a half of *Leucaena glauca* to dry enough wet beans to give one ton of dry cocoa, using a standard type of six foot by six foot rotary drier.

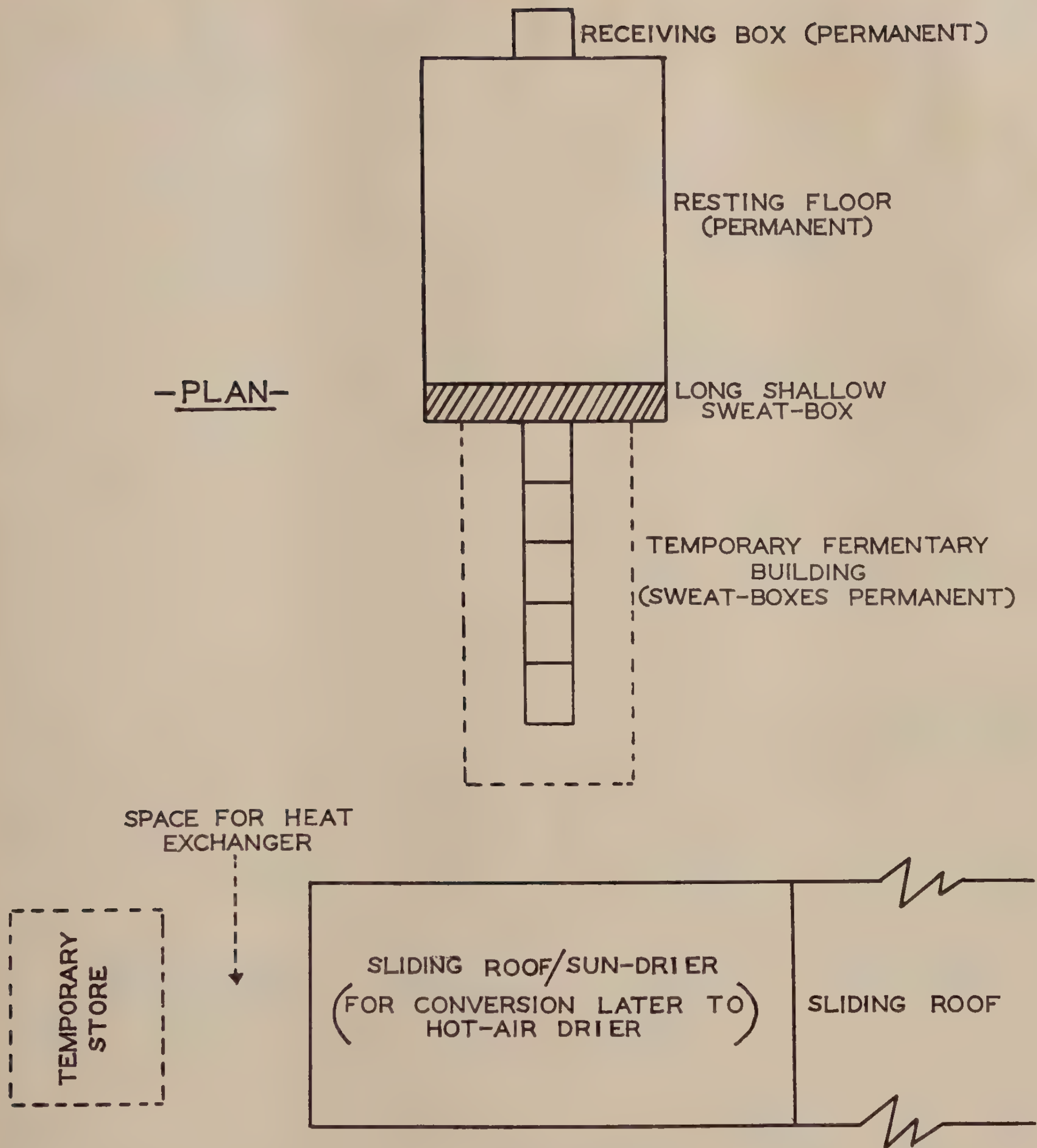


DIAGRAM IV.—*Processing plant, Stage* 1.

CLEANING AND WINNOWING

When the beans have been dried down to six per cent. moisture, it is essential to remove empty skins, very small shrivelled beans, rubbish and "doubles". Labour costs in doing this by hand are very high and it is a job which lends itself to complete mechanization.

However, none of the three types of winnowers which have been tried at Keravat can be recommended. A fourth type is to be tried in the near future.

Growers will be advised as soon as a satisfactory machine is tested. It should be noted

that we are not seeking the more expensive machines which will grade the beans into a variety of different sizes.

PRINCIPLES OF FERMENTARY DESIGN

In constructing a cacao-processing factory or fermentary, the following points are important to both efficiency and economy :—

Production Flow

Arrange for buildings and units required at successive stages of processing to be contiguous. Avoid a design requiring " doubling back " and cartage of beans over unnecessarily long distances. Aim for a continuous production line with no bottle-necks.

Balanced Units

Ensure that all equipment in the production line is balanced. For example, in Method " C ", to get a full charge for a platform/hot-air drier of 1½-ton capacity D.B.E. (Dry Bean Equivalent), each receiving box, resting floor and fermenting box must have equal capacity. It is then convenient if three complete series provide the full charge for the platform drier. The rotary drier installed must be able to cope adequately with the full discharge of the platform drier.

Planning for Expansion

The complete arrangement will rarely be achieved in a single step. It can be achieved in

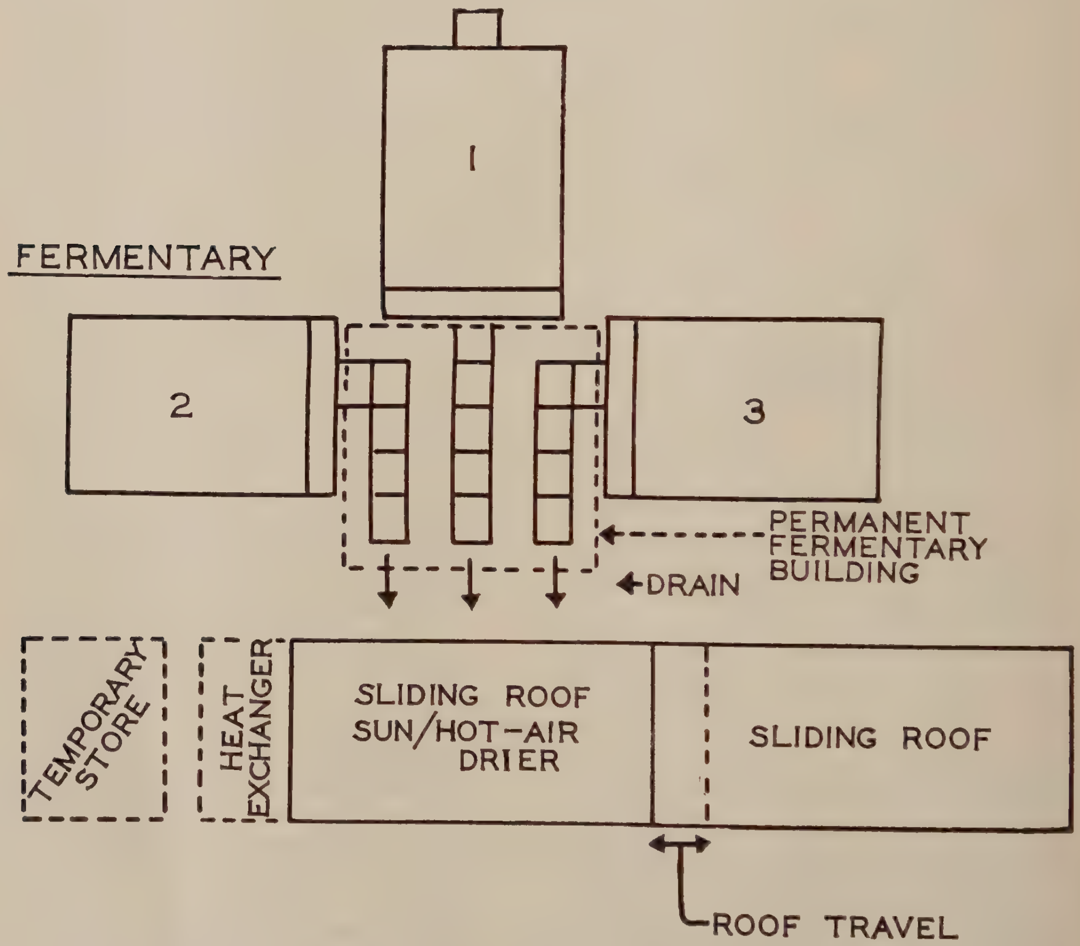


DIAGRAM V.—*Processing plant, Stage 2* (*water storage tanks not shown*).

easy stages. The fermentary should grow according to a master plan, so that growth does not lead to chaos and high processing costs.

Convenient Siting

If possible, the fermentary should be centrally situated on the plantation, or at least at a point where the majority of plantation roads converge. Buildings should be arranged so that they do not cast shadows on sun or sun/hot-air driers. Natural slopes should be utilized wherever possible to give a gravity feed through the fermentary. However, if the choice is between an inconvenient site with a slope and a convenient site without a slope, use the convenient site.

The benefit of a gravity feed is appreciable only at certain stages of processing. The level of the resting floor should be just above the level of the top of the first fermenting box. The arrangement of fermenting boxes in tiers has certain disadvantages. There is a useful gain if the level of the final fermenting box is above the level of the floor of the platform drier. By far the greatest gain is obtained if the loading platform over the rotary drier is a little lower than floor level on the platform drier. When production is high, the savings in labour resulting from the judicious use of slopes is considerable. If beans have to be carried to the highest point by hand to get the satisfaction of pushing them down an artificial slope, there can be no gain whatsoever.

DESIGN, GROWTH AND OPERATION OF FERMENTARY FOR METHOD "C"

The logical way in which drying facilities can be expanded to meet increasing production has been described above. It was noted that it is possible to begin with a sun-drier and then convert this to a forced-hot-air/platform drier. At a later stage, holding boxes and a rotary drier may be installed.

The logical concurrent expansion of fermenting equipment can now be considered.

Stage 1

Equipment—

- One Receiving Box—60-cubic-foot capacity.
- One Resting Floor (complete with shallow fermenting box)—30 feet by 20 feet.
- One Battery of five fermenting boxes—each box five feet by four feet by three feet deep (temporary roof over these boxes).
- One Sliding Roof/Sun-Drier—40 feet by 20 feet (suitable for conversion to hot-air in Stage 2).

Capacity—

About 15 tons dry beans per annum.

Stage 2

Equipment—

- Three Receiving Boxes—each of 60-cubic-foot capacity (two not shown in Diagram V).
- Three Resting Floors—each 30 feet by 20 feet (each complete with shallow fermenting box).
- Three Batteries of five fermenting boxes as above.
- One permanent fermentary building (28 feet by 25 feet, approximately).
- One Sun Forced Hot-air, Sliding-roof/ Platform Drier—40 feet by 20 feet, approximately (holding boxes optional).
- One Temporary Store for dry beans.

Capacity—

The maximum frequency of breaking will be once every four days. Theoretically, therefore, the above arrangement is capable of an output of a ton and a half of dry beans every four days or around 90 tons per annum. However, as cropping is anything but regular throughout the year, this rate of production will be given during the flush-crop by a plantation which produces only 45 tons for the whole year, which is therefore the actual capacity of the above arrangement. The equipment will work at well below its maximum capacity during the "off-crop" periods. This is inevitable and unavoidable. Yet the fermentary must be planned to cope with the flush and not the average monthly crop.

As noted above (See *Growing up with Cocoa Driers*) this capacity can be greatly increased by installing holding boxes so that a given batch occupies the drier for two days instead of four days. This then permits more frequent breaking and better use is made of fermenting equipment.

Stage 3

At this stage, all units become perfectly balanced.

Equipment—

Fermenting equipment remains unchanged. Hot-air Drier remains unchanged.

Two Holding Boxes—each of 130-cubic-foot capacity (eight feet by six feet by two feet nine inches suggested).

One Rotary Drier—a six foot by six foot rotary drier will barely cope—a seven foot by six foot rotary gives a safety margin.

One Building over Rotary Drier, holding boxes, winnower—also to provide bagging space—extend to form store for dry cocoa beans (at least 45 feet by 20 feet).

Capacity—

Disregarding management problems for the moment, this arrangement is capable of an out-turn of a ton and a half of dry beans every day of the year if the wet beans are forthcoming. Unfortunately, management problems cannot be disregarded and the beans will not be forthcoming. If the equivalent of a ton and a half of dry beans enters the fermentary five days in each week during the flush crop, this gives a theoretical capacity of 390 tons per annum or an actual capacity of 195 tons per annum. If the equivalent of a ton and a half of dry beans enters the fermentary four days in each week during the flush-crop, this gives a theoretical capacity of 308 tons per annum which corresponds with an actual capacity of 154 tons per annum. Breaking three days in each week will give an actual capacity of 117 tons per annum. The capacity at Stage 3 depends entirely on the frequency of "breaking". Figures given on capacities will also vary according to the intensity of the "flush-crop".

Management

When in constant operation, the timing of the various operations in the fermentary at Stage 3 becomes more difficult and requires greater skill in management. The fermentary will have to work to a strict schedule. The rotary drier should be discharged and recharged from a holding box by 7 a.m. The platform/hot-air drier should be discharged to a holding box and recharged from the three final fermenting boxes by 8 a.m.

Beans in all stages of fermentation should move forward by one step and, although not critical, this should be completed by 10 a.m. The resting floor will have been vacant since 1 p.m. the previous day and should receive a fresh charge at 6 a.m. This will be transferred to the long, shallow fermenting box on the end of the resting floor at 1 p.m.

Throughout day and night, both driers will require checking. All machinery must receive any necessary maintenance during operation. The fermentary must be kept clean and orderly. Dry beans must be winnowed, weighed and bagged. This is normally an afternoon job.

When operating during the flush-crop, one of the biggest difficulties is to balance the rate of harvesting with processing potential. Where the fermentary has a potential intake of a ton and a half D.B.E. per day, this requires the harvesting of some 37,000 pods daily. Depending on the terrain and compactness of the plantation, this will require a harvesting gang of 20 to 25 labourers. In practice it is safest to harvest a surplus and "break" into containers of known capacity. In this way, breaking can be stopped when fermentary capacity is reached. Surplus pods can go into the next day's breaking.

Obviously, a fermentary could not operate continually on this basis. There is no particular problem during the "off-crop" season. Even during the "flush-crop" it will be impossible to accept a full fermentary load on more than five days in each week. A break is necessary to allow cleaning of fermenting boxes, resting floors, rotary drier, etc., maintenance of machinery, etc., but the longer the breaks the lower the output and the greater the capitalization required to handle the flush-crop.

Water Supply

As output grows it becomes more necessary to have a reliable water supply at the fermentary. At Stage 1, the water consumption of the fermentary will be less than 50 gallons a day. At Stage 2, the average consumption will be more than 100 gallons a day. At Stage 3, it is estimated that 200 gallons a day will be the average requirement. A head of about 4 to 5 lb. p.s.i. is sufficient for normal fermentary operations, but higher pressure is an advantage.

Labour

Reduction in labour costs by utilizing slopes, a convenient lay-out and labour-saving devices

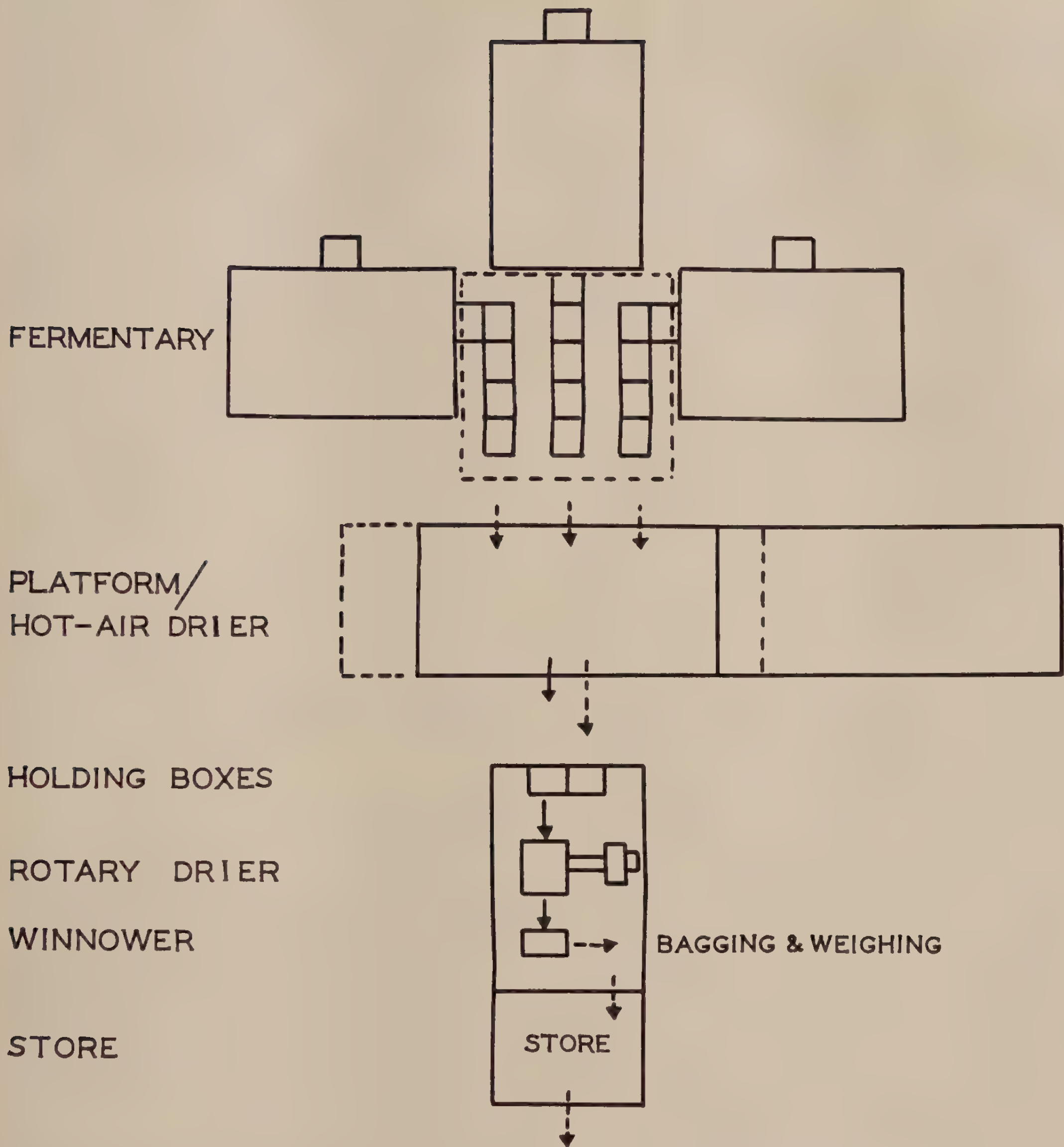


DIAGRAM VI.—*Processing plant, Stage 3 (water storage tanks not shown).*

will pay handsome dividends. The labour required at the fermentary will vary according to these factors. As a rough guide, one labourer will be required in the fermentary for every 10 tons of dry beans produced per annum. Labour costs are relatively much higher during the "off-crop" season.

Construction Detail

1. *Receiving Boxes*

Use one-inch seasoned hardwood. Dressing is not necessary but facilitates cleaning. Make the boxes durable. Drill the bottom of the box with half-inch holes on a two-inch-square pattern.

Sweatings go straight into an open drain in the ground. Place the box hard up against any convenient point around the resting floor and see that it is well covered in a way which does not interfere with loading. The level of the bottom of the box should be the same as, or a few inches higher than, that of the resting floor. The side of the box against the resting floor should be firmly hinged at the base, using brass hinges. When this side is lowered, the beans are pushed out over the resting floor where spreading can be accomplished in 10 to 15 minutes.

The dimensions of the receiving box are not critical, but it should give a capacity of 60 cubic feet. Only 52 to 55 cubic feet of beans should be placed in the box. This will give half a ton of dry beans.

If beans are broken into baskets in the field, they can drain in these baskets overnight and be dumped on the resting floor at 6 a.m. the next day. This requires a considerable number of baskets but does away with receiving boxes.

2. *Resting Floor*

Only very light construction is required. It is sufficient to place bearers 10 feet apart and joists at four feet. Place two extra joists under the long, shallow fermenting box at the end of the resting floor. The floor of the resting floor can be of undressed six-inch by one-inch hardwood but cleaning is facilitated if the timber is dressed on the upper surface. The planks should be spaced at an eighth to a quarter of an inch so that water used in washing can run through to the ground. There are no sweatings during the resting phase and no provision has to be made for drainage.

The resting floor should be 30 feet by 20 feet for each charge of half a ton D.B.E. Where a double floor is required, two separate 30 foot by 20 foot floors should be used in preference to one 40 foot by 30 foot floor. The object is to achieve the maximum possible air-movement over the floor so there is a decided advantage in keeping the floors long and narrow.

The roof should be kept as close to the floor as possible to give the maximum build-up of air temperature over the beans. This also reduces walling costs. It is sufficient to have just enough clearance between roof and floor for convenient working. Probably the best arrangement is to have a skillion roof giving four- to five-foot clearance on one side of the floor and seven to eight feet on the other side. A wall on the low side is then unnecessary, provided there is sufficient overhang. On the high side, install a six- to seven-foot overhanging projection (Diagram VII). No further walling will then be required on this side. Where two resting floors are parallel and adjacent, reverse the pitch on the two skillion roofs and use a single well-jacked ridge over the junction of the roofs. An end wall should be installed at the receiving end. Project the roofs two to three feet past the ends. Leave a gap of one foot between top of end wall and roof.

The roofs of the resting floor and the fermentary building should overlap. This removes all necessity for an end wall on the fermentary end of the resting floor.

Galvanized iron is preferable to aluminium as a roof over the resting floor. It absorbs more heat, is more durable and is not subject to corrosion during this phase. The upper surface may be painted black, but this is not essential.

The height of the floor can be adjusted to suit the topography. It can be placed as low to the ground as 12 to 18 inches.

3. *Long, Shallow Fermenting Box*

The dimensions of this box may be variable except for depth, *which is critical.* A three-foot-wide box one foot deep and running the full width (20 feet) of the resting floor will give the required 60-cubic-foot capacity. A shorter box 15 inches deep is equally satisfactory, but under no circumstances should the box be made any deeper. A box 10 feet by six feet by one foot would be satisfactory and may be somewhat easier to unload into the first standard fermenting box.

The floor of this box is formed by part of the resting floor and must be drilled on a four-inch-square pattern with half-inch holes. These holes must be kept clear. Heat will be conserved if the box is double-walled. At Keravat, this box is double-walled using tongue-and-groove flooring. For convenience of loading into the first standard fermenting box, the outer wall of the shallow fermenting box may carry a gate, hinged at the bottom (brass hinges), so that when lowered it serves as a chute into the first standard fermenting box.

4. *Standard Fermenting Boxes*

These boxes should be constructed in batteries of five. Construction recommended is the same as described by Henderson (1954) with the exception that the "Vee Drain" running the full length of the battery, while desirable, is not essential. There are no "sweatings" from the beans in these boxes. Drainage is required to take away water used in washing. The fermenting boxes must be raised some four inches above the concrete floor so that air can be taken in through the bottom of the boxes. If the whole floor of the fermentary building has a slight fall to a single open drain (Diagram V) at the front of the fermentary building, this provides adequate drainage. Sluice the whole floor regularly.

ridge capping is raised two inches. If skillion, leave a gap along the top of the highest side to permit the escape of acid-laden air. The underside of the roofing iron should be painted with acid-resisting paint *before* it is put up.

Construct the fermentary building in such a way that cooling winds do not increase radiation losses from the fermenting beans, but allow for some air-movement to remove acid vapour. A one-foot space is sufficient between the top of any walls which may be required and the roof.

6. *The Sun/Hot-air Platform Drier*

Site as close to the fermentary building as possible without getting a shadow falling on the drying floor (Diagram V). If the drier is oriented in an east/west direction, it need be

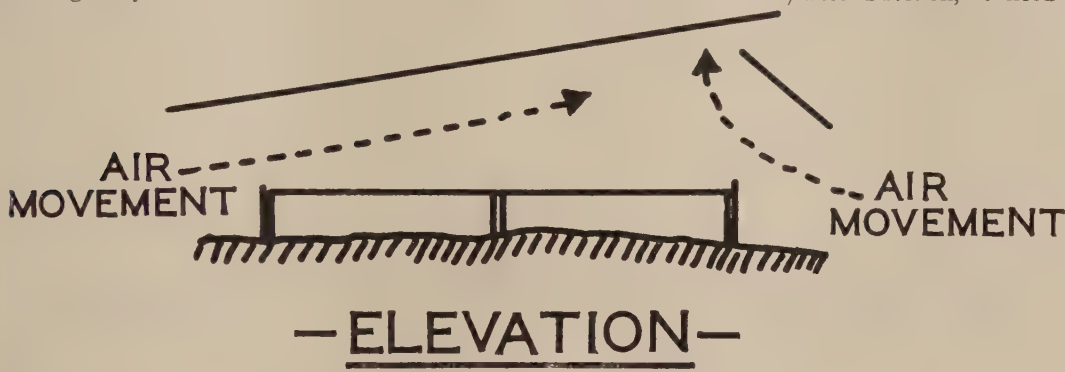


DIAGRAM VII.—*Design of resting floor.*

The standard fermenting boxes are three feet deep but should not be filled to a greater depth that two feet nine inches (half a ton D.B.E.) under normal circumstances.

5. *Fermentary Building* (covering the standard fermenting boxes).

Drainage requirements have been noted above. At Stage 3, a building 28 feet by 28 feet is required. Concrete the floor throughout. With Method "C" there will be no problem of corrosion of concrete.

Post height of the building will be determined by the site but should be high enough to give a close overlap of the roofs of the resting floors and the fermentary building. The roof must also be high enough to allow ample working room over the fermenting boxes and may be "skillion" or "gable". If gable, the ridge should be "jacked" a few inches. This will reduce corrosion. It is sufficient if the two-foot

only 10 to 12 feet away from the final fermenting boxes.

7. *Building for Rotary Drier, Winnower, Bagging and Store*

Site as closely as possible to the Sun/Hot-air platform drier without casting a shadow on it. The building should be at least 20 feet wide.

The length of the building, sufficient to house holding boxes, rotary drier and winnower, should be at least 30 feet. If the drive on the rotary drier is through a series of long belts and countershafts, the building will need to be longer. A more direct and compact type of drive saves space and is safer.

The building should be extended to provide a store for bagged cocoa. The length of this extension will depend on how often the grower can ship his dry beans. An extension of 15 feet to make the building 45 feet long will give comfortable storage space for more than 10 tons of bagged cocoa.

If there is a convenient fall from the platform drier to the top of the drum of the rotary drier, wall heights should be adjusted so that wall-ties, when suitably strengthened, can carry the loading platform above the rotary drier. If this is to be done, a " truss " roof will make for ease of working on the loading platform. In such a case, the holding boxes can be installed on the loading platform. They could even be placed on rails running between the platform drier and the rotary drier.

If there is a " lift-up " from the platform drier to the loading hoppers over the rotary drier, as will frequently happen, then either the rotary drier should be so sited in the building that wall-ties do not interfere with loading, or the building should have 12-foot posts so that any ties are well out of the way. Only low (eight-foot) walling is required on this building.

USEFUL FIGURES

A cubic foot of wet beans usually weighs about 56 lb. on arrival at the fermentary.

At the end of the resting phase in Method " C " a cubic foot of beans will weigh 46 to 48 lb.

At the end of fermentation a cubic foot of beans weighs 42 to 44 lb.

At the end of drying a cubic foot of beans weighs about 40 lb.

A cubic foot of beans from the pod contains 7,000 beans (approximately). At the end of fermentation a cubic foot of beans contains 7,650 beans (approximately). At the end of drying a cubic foot of beans contains some 13,000 to 14,000 beans (rotary dried).

It is evident from the above that during drying there is about 50 per cent. loss of both weight and volume as compared with wet *fermented* beans.

Comparing wet *unfermented* beans with " dry " beans (six per cent. moisture), the recovery of dry beans after complete processing is usually 38 to 40 per cent.

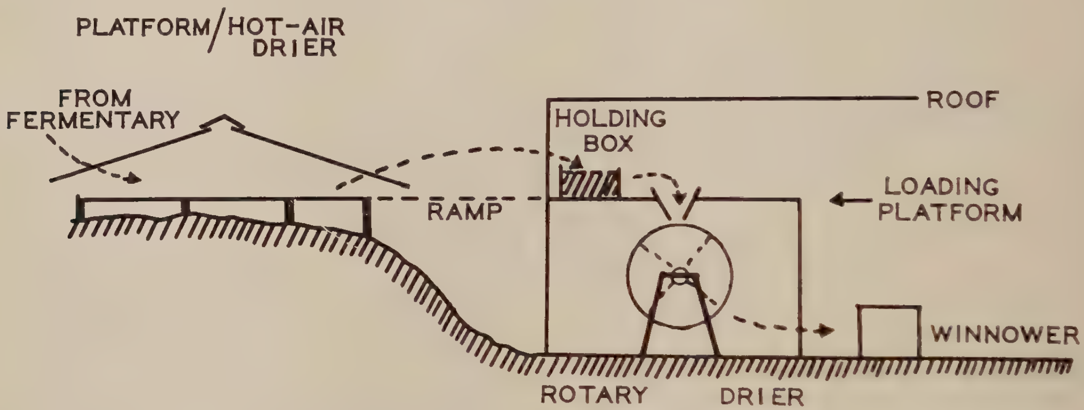


DIAGRAM VIII.—*Split drying (ideal loading arrangement).*

The ridge on this building should be " jacked " to prevent the accumulation of acid-laden air. The floor should be concrete throughout. In the " store " section, the concrete floor should be covered with open duck-boards so that bagged cocoa does not lie on damp concrete. Walls of the store should be unlined to avoid harbouring insects. A ceiling in this section of the building is desirable. When doors and windows are closed, it can then be effectively fumigated if insect infestation becomes apparent.

8. *Labour Quarters*

Suitable quarters for the specialist fermentary gang should be installed within calling distance of the fermentary.

60 cubic feet of wet beans yield 1,344 lb. dry beans, 55 cubic feet of wet beans yield 1,232 lb. dry beans.

Three batteries of standard fermenting boxes each filled to two feet nine inches to give 55 cubic feet will yield 3,696 lb. dry beans at each discharge—i.e., just more than a ton and a half. The equivalent in wet unfermented beans is 9,240 lb. When fermented, this quantity of beans will weigh 7,115 lb. and will occupy 156.75 cubic feet. As a rough guide, after 24 hours' drying on a platform/hot-air drier, the weight will be reduced to 5,330 lb. and the volume to about 120 to 125 cubic feet. When fully dry, the ton and a half of dry beans occupies a volume of 82 to 94 cubic feet.

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ACKNOWLEDGEMENTS

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The Department is indebted to the Tolai fermentaries for supplying beans to assist our work programme when our own crop has been inadequate.

The assistance of Australian chocolate manufacturers is again acknowledged with thanks.

PLATE 1.—*Seedlings at selection stage in nursery.*

NURSERY SELECTION OF COCONUT SEEDLINGS

A. E. CHARLES.*

THE importance of careful selection of planting material when establishing a new area of coconuts cannot be over-emphasized. Any mistakes made in the initial planting will reduce the returns to be expected from the crop over a period of 50 years or more so that some additional expense in the first instance will be amply repaid in future years.

An experiment carried out in Ceylon (Liyanage 1955) has shown convincingly that very worthwhile improvements in future plantation productivity can be achieved by selection of seedlings in the nursery. Three criteria of selection are used :—

(*a*) early sprouting ;

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(*b*) vigour of seedling; and

(*c*) resistance to pests and diseases.

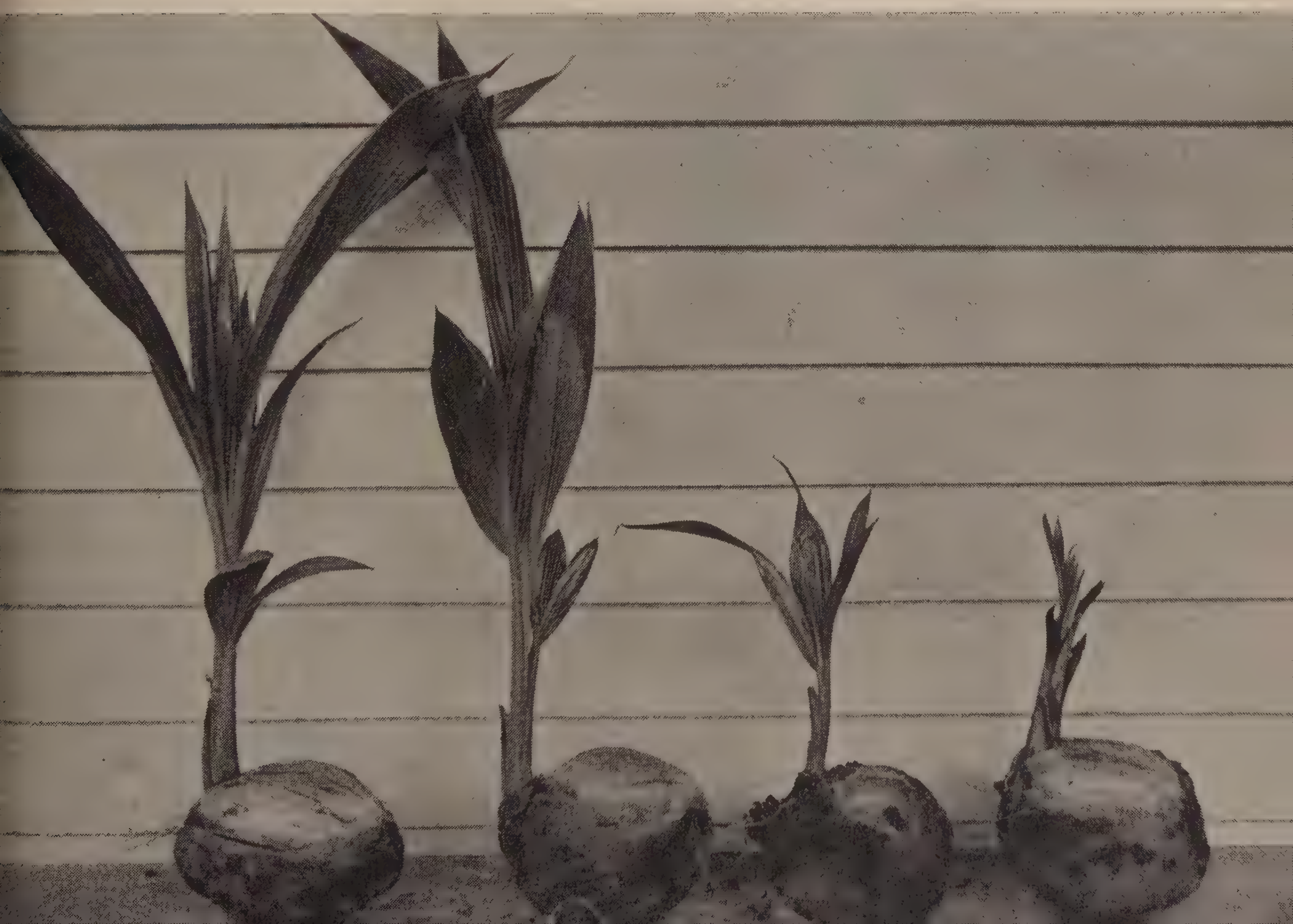
The experiment referred to was laid down in 1939, and palms had been in bearing for nine years at the time the results were reported. It has shown that there is a definite correlation between the time taken for a seed nut to sprout and the time taken for the palm to mature and commence flowering. Early sprouting nuts on the average produce earlier flowering palms than nuts which are slow to sprout. Thus palms grown from early sprouting nuts give higher yields in the first years of bearing.

The experiment has also shown that the yield of nuts from palms derived from selected seedlings has been significantly higher than those derived from unselected seedlings. The increase in crop in both number of nuts and weight of copra during the first five years of bearing (1945-1949), was over 25 per cent. and subsequently (1950-1954) more than 12 per cent. This increased yield in the early years would more than repay the cost of selection, even if the advantage were not maintained in later years. However, indications are that the advantage will be maintained throughout the life of the stand.

Seed Collection

One factor which is likely to reduce the effectiveness of seedling selection in this country, as compared with Ceylon, is the difference in method of harvesting. In Ceylon, nuts are cut down from the palms as soon as they mature, and thus it is possible to obtain seed nuts of uniform age for planting. In this Territory, nuts are collected from the ground after natural fall and inspection of the palms on any plantation will show that this leads to considerable variation in the age of the fallen nuts. Many palms tend to drop their nuts as soon as they

PLATE 2.—*Seedlings at selection stage contrasting good characteristics* (*left*) *with poor ones.*



mature, when the husk is brown, but not fully dry. But on some palms the dry nuts hang for some months before falling, and often are germinated or infected by the time they fall. Such variation in age will inevitable cause variability in rate of germination not related to the vigour of the seed.

It is therefore important to collect seed as uniform in age as possible. Freshly fallen nuts only should be taken and those palms should be avoided which have more than one bunch of dry nuts hanging on them. If the quantity of seed required is not too great, it may be worthwhile to collect from the palms in the same way as in Ceylon.

Nursery Practice.

The nursery should be established in even, well-worked and, if possible, fairly loose soil, preferably where water is available for watering in dry periods. Nuts should be spaced widely enough to enable removal with a large proportion of the roots after the seedlings have been selected at about the four-leaf stage. A spacing of about 12 inches in rows, 18 inches apart should be satisfactory. Seed nuts should be planted on their side and at such a depth that they are almost covered by the soil.

The first selection to be made will be based on the time taken to shoot. Ceylon practice is to reject all seed nuts that do not germinate within 20 weeks. However, rate of germination is affected considerably by weather conditions—dry weather slows germination—and a more satisfactory criterion might be the rejection of all ungerminated nuts as soon as the first 70 per cent. have shot. These nuts could still be converted to copra.

The second selection is made on the vigour of the seedlings. The time of this selection must be to some extent a compromise. The older the seedling, the easier it will be to detect differences in vigour. But on the other hand, the older the seedling, the greater will be the setback at transplanting, particularly if weather conditions prove unfavourable. As a compromise, the four-leaf stage (that is, when the majority of seedlings have four leaves) is the best for selection. But in areas where rains cannot be relied on, it would be better to select and transplant earlier.

Vigour is determined from the girth at the base of the shoot ; size, spread, and colour of the leaves ; rapidity of growth and sturdiness of the seedling. A good seedling has a stout stem, dark green, broad leaves with strong midribs. A poor seedling is "leggy" with a thin, weak stem, pale green, narrow leaves and thin midribs.

On these standards, the two stages of selection will probably result in rejection of 40 to 60 per cent. of the original seed nuts. This will at least double the cost of planting material over the use of unselected material ; but as has been indicated, the extra expense will be abundantly repaid. In any case, cost of planting material is a minor item in the total costs of coconut planting.

REFERENCE

Liyanage. 1955. Planting Material for Coconuts. Ceylon Coconut Quart., 6 : 75-80.

THE COCONUT LEAF-MINING BEETLE PROMECOTHECA PAPUANA*

J. L. Gressitt.

The severe depredations of the coconut leaf-mining beetle, "Promecotheca papuana", have been noted by many observers on coconut plantations in New Guinea. The author, Chairman of the Entomology Department of Bishop Museum, Honolulu, who made a detailed study of the ecology of the pest in 1956 *and* 1957, *draws attention to the "one-stage" nature of the infestation, when it reaches plague proportions. In this detailed review, Dr. Gressitt acknowledges published and unpublished material assembled by workers in New Guinea. He concludes that although much still remains to be learned about the factors leading to the outbreaks it is advantageous for planters to take steps to encourage predators of the beetle, such as lizards, birds and the kurukum ant.*

THE coconut leaf-mining hispine beetle, *Promecotheca papuana* Csiki (*P. antiqua* Weise, *P. biroi* Csiki) is a serious pest on coconut plantations in some parts of New Britain and Manus Island. This leaf beetle periodically attains plague proportions in these areas, when it exists in the "one-stage condition" as described below. Otherwise it is usually under good control by natural enemies.

In New Britain the areas principally affected are the Linga Linga area and some others on the north coast of central New Britain, west and east of the Willaumez Peninsula, the Lindenhafen area and others on the south coast of central New Britain, and parts of the Gazelle Peninsula at the north-east end of New Britain. Of the three areas, damage has been most severe at Lindenhafen Plantation, and generally least severe on the Gazelle Peninsula. A serious outbreak occurred on the Gazelle Peninsula in 1937, but was correlated with the great volcanic eruption of May, 1937, which caused damage to the palms and probably also seriously affected the native parasite populations.

Other lesser outbreaks have been reported from various parts of New Britain, the Duke of York Islands, and Manus Island. The species also occurs in New Ireland and north-east New Guinea, but has not been recorded as a pest from those areas.

Outbreaks of this leaf beetle appear to occur in cycles of about once every 10 to 15 years in some of the areas mentioned. Correlation with climatic cycles has been difficult because of insufficient records.

This beetle was recognized as a major pest in the period of German administration, and the kurukum ant (*Oecophylla smaragdina*) was used as a controlling agent (Friederichs, 1920).

In early 1937, G. H. Murray, Director of Agriculture, visited Lindenhafen and in his report (1937) includes the following paragraph :

* This paper draws on published material by B. A. O'Connor, formerly Assistant Entomologist in the Territory of New Guinea and now Senior Entomologist, Department of Agriculture in Fiji, and unpublished material from C. S. Dun, Principal entomologist, and J. H. Ardley, Entomologist, of the Department of Agriculture, Stock and Fisheries, Territory of Papua and New Guinea. (Paper received for publication 15th June, 1959.)

"The estate presents a dreadful appearance and it is the worst infestation of *Promecotheca* of which there is any record in the Territory. When walking through the plantation one hears on all sides the continual drop of immature nuts which the palms can no longer sustain. Many of the trees have already succumbed, 370 dead palms having been cut down and destroyed, while there is not a single flower spathe on the whole plantation, so that no crop can be expected for two years, even from those trees that do eventually recover."

In 1938-1939 B. A. O'Connor studied the beetle, first in Manus and then at Lindenhafen Plantation in southern New Britain. His report (1940) was preceded by those of J. L. Froggatt (1936, 1937, 1939 and 1940). Summaries of this and other New Guinea coconut insects were published jointly by Froggatt and O'Connor (1941).

The parasite *Pediobius* ("*Pleurotropis*") *parvulus* which was so successful in controlling *Promecotheca caeruleipennis* ("*reichei*") in Fiji (Taylor, 1937), and to some extent *Promecotheca opacicollis* in the New Hebrides, was introduced into New Britain in October, 1938, from Fiji and became established and abundant. However, it has failed to prevent recurrence of outbreaks. In 1953-1954 simultaneous serious outbreaks occurred at Lindenhafen and Linga Linga Plantations. The outbreaks were observed by J. H. Ardley (1954) at these two plantations and at several others, mostly on the south coast.

After this I was asked by the Territory of Papua and New Guinea to study the ecology of the beetle. This I did for two months, April and May, 1956. The plan was to spend the time at Linga Linga and Lindenhafen Plantations. However, after about ten days at each a moderate outbreak was reported from Vunakanau Plantation on the Gazelle Peninsula. My second month was spent at Vunakanau and nearby plantations. In all I visited 20 plantations besides the three which were principally infested (Gressitt, 1958; 1959b). I had the opportunity to revisit Vunakanau three times (early and late July, 1956; October, 1957) after my month of study there. Mr. Ardley accompanied me during my visit to Linga Linga, and also during part of my stay at Vunakanau.

METHODS

O'Connor (1940) used the following methods in rearing and observing *P. papuana* :—

"One or more pairs of newly-emerged adults were placed in wire sleeves attached to a growing palm in such a way as to contain several leaflets. The wire sleeves were cylindrical, about 18 inches long and four inches in diameter, and at each end were continued into cloth cylinders about six inches long, which served to close the wire cylinder, and render it beetle-proof. Palms of from six months to a few years old were used, as their foliage is more easily accessible. When the palm used was only a few feet high, a stake was placed in the ground a few feet away and one end of the cylinder attached to a piece of twine coming from the end of the stake. Thus the weight of the cylinder was largely supported by the stake. When older palms were employed, a piece of tie-wire was passed along one side of the cylinder, and was attached to the midrib of the frond.

Cotton-wool wrappings were always used to ensure that the cloth fitted tightly over the leaflets, as otherwise the beetles were able to escape.

When food became exhausted, or when several egg-masses had been laid on the leaflets, the beetles were moved to fresh leaflets. Egg-masses were marked, and the development of the eggs and larvae followed up. Life histories of larvae were worked out also in the laboratory, where larvae could be carried through in leaflets kept in water, being put into mines in fresh leaflets whenever necessary."

O'Connor treated various aspects of the problem, but concentrated on working out the biology and determining the parasites, at Manus in 1938 and at Lindenhafen in 1938-1939.

Ardley (1954) spent the greater part of his effort on palm surveys at Linga Linga Plantation, determining severity of attack, density of population of the beetle, degree of parasitism and other aspects, by the spot-check, transect methods, sampling fronds cut down from palms climbed by plantation workers, and by comparative observation. He classified palms in eight categories relating to extent of damage by the beetle

(Table VI). Ardley also tabulated the correlation of presence of kurukum ants (*Oecophylla*) with degree of damage by the beetle, as discussed below.

I attempted to follow the methods and surveys of O'Connor and Ardley as far as possible to check facts and to obtain comparative data. I also tried to approach the problem from the broad ecological standpoint, taking into consideration all possible factors which might bear upon the problem. In the daily field work, the populations of *Promecotheca* and other insect inhabitants of individual palms were analyzed. Particular attempts were made to note the relationships of ants and various arthropod, or vertebrate predators of the beetle, as well as those of the beetle's parasites. Some observations differing from the conclusions of earlier workers were made.

To check data on the life-history of the beetle, daily observations were made by marking egg-cases or mines in the field, making measurements to determine periods of feeding and rest or transformation. Large numbers of the beetles, in various stages, were collected and caged in various ways to determine the nature of parasitism and other aspects. I used organdie sleeve bags instead of the wire sleeves used by O'Connor.

Certain palms were examined to determine changes in the beetle populations, and to evaluate predation. Mating pairs of beetles were caged with daily inserted fresh leaflets, supplied with water, to permit recording extent of oviposition. Adults were caged with various possible predators, such as lizards, ants, earwigs, spiders, and others. Observations were made upon nearly 600 palms, a number of them on several occasions.

THE GENUS *Promecotheca*

The chrysomelid genus *Promecotheca* contains at least 35 species, of which two are recorded from the mainland of East Asia (one questionable), one from Borneo, seven from the Philippines, one from Java, two from Celebes, one from the Moluccas, three (plus three new species) from New Guinea and nearby islands, three from northern Australia, two from the Bismarck Archipelago, ten (plus some new species) from the Solomon Islands (including Bougainville), one from New Hebrides, Santa Cruz and Banks Island, and two from Fiji, one of which, *caeruleipennis,* is also known from Tonga and Samoa. Thus the group has a predominantly Philippine-Papuan distribution. It is distinctly tropical, the species occurring mainly at low altitudes (Gressitt, 1959a).

All members of the genus are leaf-miners in monocotyledons. Seven of them feed upon coconuts, and all these have been recognized as pests. They occur in Malaya (Burkhill, 1918), Borneo *, Java, Celebes, Moluccas (Kalshoven, 1951; 1957), Philippines (Jones, 1913), parts of New Guinea, the Bismarcks, the New Hebrides (Kowalski, 1917; Risbec, 1935), Fiji, Tonga, and Samoa. No coconut *Promecotheca* has been recorded from the Solomons, except the Santa Cruz Group (Lever, 1933; Pagden and Lever, 1935), and none for certain from Australia (Froggatt, 1914) or most parts of the New Guinea Mainland. Some of the coconut species attack other palms as well, particularly other species such as nipa palm, sago palm and betel nut palm. About ten species mine only in leaves of palms other than *Cocos.* Most of these occur in the Solomons. About eleven species mine in leaves of *Pandanus* (one of them also is *Freycinetia*). Most of these are in New Guinea and the Philippines, with a few in the Bismarcks, Solomons and northern Australia. Two in the Solomons mine in ginger leaves. One species is known from *Flagellaria,* in Fiji, and one from sugar cane and other large grasses in the eastern Solomons (Gressitt, 1957, 1959a).

A Fiji member of the genus, *P. caeruleipennis* (*reichei*) was studied and reported in great detail (Taylor, 1937). This species differs, among other points, from *papuana,* in having only one egg per ootheca, and thus only one larva per mine, instead of three to five. The Fiji species was a serious pest of coconut, but was remarkably well controlled by the hymenopterous parasite *Pediobius* ("*Pleurotropis*") *parvulus* which was introduced to Fiji from Java for this purpose. Another species, *Promecotheca opacicollis* of the New Hebrides, also an important coconut pest, has been fairly-well controlled by the

* Gater [1924, Insect pests of Labuan and adjacent islands. Malayan Agric. Jour. 12 (11): 374-376] does not list *Promecotheca* from Labuan Island. However, on 24th October, 1957, at a small farm northeast of the airstrip on Labuan, I found *P. cumingi* very abundant and apparently in the one-stage condition, as adults and old mines were numerous, but no larvae could be found.

same wasp. Two species, *P. nuciferae* and *P. soror,* are coconut pests in Celebes and the Moluccas, but may represent a single species. The closely related *P. cumingi* is a serious pest of coconut in the Philippines, Borneo, Java and Malaya.

A second species in New Britain, *P. straminipennis,* was found during this study, at Vunakanau, to mine in the leaves of a tree-like *Pandanus* in the larval stage and to feed on the undersides of the same leaves in the adult stage (Gressitt, 1957). This species is much larger than *P. papuana* and appears not to share the same parasites. Another still larger species on Bougainville (*P. violacea*), mines in leaves of a large *Pandanus* and has up to at least seven larvae in a single mine.

In general, individuals of *Promecotheca* are very scarce on their native hosts under natural jungle conditions, but may become abundant under plantation circumstances or in village areas. I have noticed this for pandanus species as well as for palm species.

Copeland (1914), following Preuss (1911), states that in New Guinea *P. papuana* is specially liable to attack palms standing in grassy (*Imperata cylindrica*) areas, but that the beetles disappear when the grass is eradicated. This is probably a wrong deduction based on some coincidence.

BIONOMICS AND STAGES OF *Promecotheca papuana*

Host plants

The preferred food plant of this beetle is the coconut palm. The original native hosts, however, may have been the nipa palm and the sago palm. Of the latter two the nipa palm seems to be definitely preferred. O'Connor cited two species of palms as hosts in addition to the coconut palm : *Metroxylon sagu,* the sago palm, and *Elaeis guineensis,* the oil palm. The latter is not native to New Britain, and the larvae from eggs laid upon it (only in severe infestations) die after the first or second day of feeding. *Nipa fruticans,* the nipa palm, had been recorded as a host by Froggatt (1914) and others, and Ardley and I found ample evidence of the beetle developing and maturing in this palm at Linga Linga and westward on the north coast. Thirty-two adults and many larvae or pupae were taken from 24 mines in nipa.

At Vunakanau I found a population breeding in a group of betel-nut palms, *Areca catecu,* Interestingly enough, this group of betel-nut palms was surrounded by tall coconut palms which were almost unaffected by the beetle. The former, a group of six young to half-grown *Areca,* were quite densely populated by adult beetles, with much adult feeding damage (Plate 4A). Egg-cases and a number of larvae (Plate 4B), as well as mature mines from which adults had emerged, were also observed. A single adult was observed on a young betel-nut palm near a seriously affected part of the plantation, but betel palms in other parts of the plantation were not affected. It appears unlikely that outbreaks originate in native hosts, but they may occur concomitantly in hosts other than *Cocos,* adjacent to plantations.

Relationship to host

This beetle is very closely attached to the coconut palm, with all stages occurring in the palm crowns. Like other hispine beetles, it is destructive to the host both in larval and adult stages. It is a weak flyer, and rarely flies far at one time. If dislodged, or brought to the ground on a cut frond, an adult will almost always fly straight up to the palm crown again, or at most to the next nearest palm if the palms are tall. If part of the frond on which it was brought to the ground is projecting above the surroundings, the beetle may alight on leaflets of this higher portion. Thus the beetle is not a rapid spreader and is not known to migrate. Infestations apparently do not spread from one area to another to any great extent. If the beetle is widespread, it is apparently the result of a general local condition obtaining, such as factors working against the parasites or against most of the natural enemies.

The larvae spend their entire existence in the mine between upper and lower surfaces of a leaflet. After being mined, both surfaces of the leaflet turn pale brown, or dark brown when wet. The effect of this under conditions of dense population is to destroy all green tissue of the middle and lower fronds, rendering them dry and brown as if burned or killed by coconut blight. The adults spend their time on the undersides of the leaflets of the lower or middle fronds, going to newer fronds to feed or oviposit under crowded conditions. In serious outbreaks they complete the destruction of green tissue by

PLATE 1.—*Adult feeding on coconut fronds, Vunakanau, May,* 1956.

feeding on all the fronds not mined by larvae (Plate 1). Thus a plantation may turn completely brown.

In some cases the central shoot may be seriously damaged, leading to death of the palm. However, recovery is the general rule. Palms thought by Ardley to be dying during his 1954 survey proved to have revived by 1956, although they had not started bearing nuts again. Possibly some of the palms described in the quotation above from Murray as cut down at Lindenhafen might also have revived. At any rate, severe outbreaks set back nut production for at least two years.

Age of palms attacked

In general, *Promecotheca* appears to prefer mature palms. Actually the governing factor appears to be exposure to sunlight. Hispines are sun-loving insects, being strictly diurnal, although many spend much of their time hidden within plants. Younger palms, or palms lower than neighbouring ones, are usually less liable to attack than mature palms. Individually, isolated palms are particularly vulnerable. Young palms well away from the shade of mature palms or other shades are susceptible to attack, and all ages of palms are actually suitable for any stage of the beetle. However, new plantings of coconuts have not been observed to be seriously attacked.

During this survey, at Linga Linga and Lindenhafen, it was noted that almost all the *Promecotheca* of various stages were found on young palms. These young palms were largely within the shade of taller palms, which contradicts the above generalization. The reasons for this are not clear. I suspect that it was a reaction to some of the results of, and factors contributing to, the termination a short time before of the severe outbreaks at the two localities. These factors included the severe damage to the mature palms, which for some time eliminated plant tissue suitable for food or oviposition for the

beetle, the great build-up of parasites and predators in the mature palms, also contributing to the elimination of the beetle population in those palms, and the general slowness of the beetle to move to new situations following the rejuvenation of the badly attacked palms. This explanation may not be completely satisfactory, and some other contributing factor may have been overlooked.

At Volupai where no serious outbreak had occurred, most of the population was also on young palms. As I went first to these three plantations, I concluded that the beetle preferred young palms, contrary to the case with the Fiji *Promecotheca.* However, this situation is apparently abnormal, and the New Britain species is normally sun-loving like the other species.

The eggs

The eggs (Plate 2 and Fig. II) are flattish, oval-elliptical, nearly white, with lower surfaces striate from attachment to the leaflet undersurface while soft. They are encased in a whitish buff ootheca, or egg-case, of partly digested fragments of coconut leaflet surface covered with a transparent mucilage., Both materials are ejected from the anus of the female. The egg is about 2 x 1 mm., and the ootheca is nearly round in outline, not very strongly convex, and 3-4 mm. in diameter. In the Lindenhafen area there are often five eggs per case, whereas on the Gazelle Peninsula and on Manus Island there are usually only three per case (2.97 average in 316 oothecae at Vunakanau).

The eggs are laid on the undersurfaces of the frond leaflets, sometimes one-tenth of them on the upper surfaces in overcrowded conditions. They are laid parallel, generally two beneath and one above, or three below and two above. After depositing the eggs the female covers them with the above-mentioned materials, taking at least half an hour for both processes together. She becomes rather active and excited towards completion of the process and at the end she

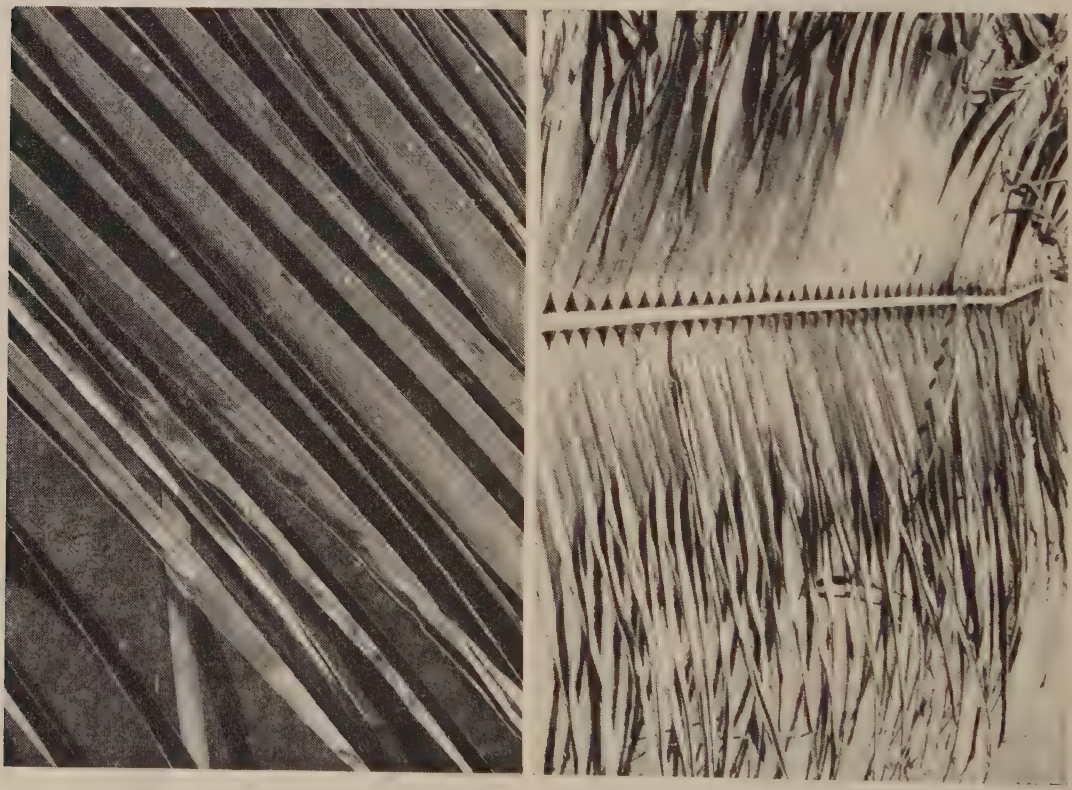


PLATE 2.—*Egg-cases on undersides of coconut fronds, Vunakanau, May, 1956.*

PLATE 3.—*Larval mines on coconut fronds, Vunakanau, May, 1956.*

reverses and pats the surfaces of the ootheca with her fore legs in a most ludicrous manner, moving all her legs and almost dancing about the sides of the egg case for nearly two minutes. The fresh case is pale green but turns straw-colour on drying.

Egg-laying generally takes place during the last hour of daylight but twice I observed it at Vunakanau in mid-morning. Before ovipositing, the female chews a slit in the leaf surface, over which the eggs are laid. On hatching, the young larvae enter directly into the inner leaf tissue by means of this slit. The larva, young or old, is unable to penetrate an undamaged leaf surface, as its mandibles point directly forward and work pincer-like in a horizontal plane.

In heavy infestations, and on young palms, eggs are laid on the new fronds, even the newest one before it is fully opened. The larvae from five or six egg cases (four for Lindenhafen) can mature in one large leaflet. But in the outbreak at Vunakanau the following numbers of cases were counted on single leaflets, indicating great waste of biotic potential : 14, 19 (two cases) ; 22, 23 (three cases) ; 24, 25 (three cases) ; 29, 31 and 32.

Larva

The larva (Figs. I and II) is a flattish, creamy white grub with heavily skerotinized head and mouth parts, from golden-brown to reddish-brown in colour anteriorly.

Technical description : Newly-hatched larva white with prothorax testaceous, but dark above front part of head, and occupying two-fifths length of body ; head capsule nearly parallel-sided, about as long as prothorax ; body length 1.6 mm. ; breadth 0.8 mm. Mature larva creamy whitish ; head capsule partly blackish anteriorly ; prothorax pale brown, transparent at side. Body about three-fifths as deep as wide, gradually tapered from mesothorax. Head capsule slightly broadened posteriorly, constricted between middle and apex, rounded at

anterior and posterior angles, with four black dots at side behind antenna ; labrum obtusely emarginate apically ; antenna with second segment strongly oblique and third segment short with long setae. Prothorax strongly convex anteriorly and slightly convex posteriorly in dorsal outline, three-lobed, each lobe feebly convex, the lobes separated by narrow, deep emarginations, apical portion finely asperate-granulose, its margin slightly irregular ; lateral margin with fine setae, in particular anteriorly. Meso- and metaterga fairly smooth. Abdominal tergites one to eight each finely reticulate, with a transverse groove with raised borders, a short, longitudinally oblique groove just beyond end of this, and side rounded, with a low round spiracle followed by three setae and five or six setae arranged vertically but somewhat irregularly on lateral swelling ; ninth tergite plain, with a number of setae near posterior angle ; tenth tergite short, bearing an erect triangular process on middle and a pair of small nodes just above anal opening, all three slightly pigmented. Length 12 mm. ; breadth 2.8 mm.

The larvae always remain within the mine (Plate 3, Fig. II), and are thus never exposed. They may readily be seen while feeding by holding the leaflet against the light. They are then in the green, not yet dried terminal portion of the mine, whereas when moulting, or when badly disturbed, they retreat to the already dried, opaque portion of the mine. They feed upon the parenchyma tissue, cutting through it by the pincer-like action of the jaws, leaving upper and lower epidermis intact. Because of the structure of the coconut leaflet, the upper surface of a mine is thinner than the lower surface.

Generally the larvae in one mine feed side by side, and stop feeding at the same time to rest or moult. They work forward from the egg-slit where they entered the leaflet tissue, chewing a wide swathe and leaving behind common deposits of excrement of a sawdust-like

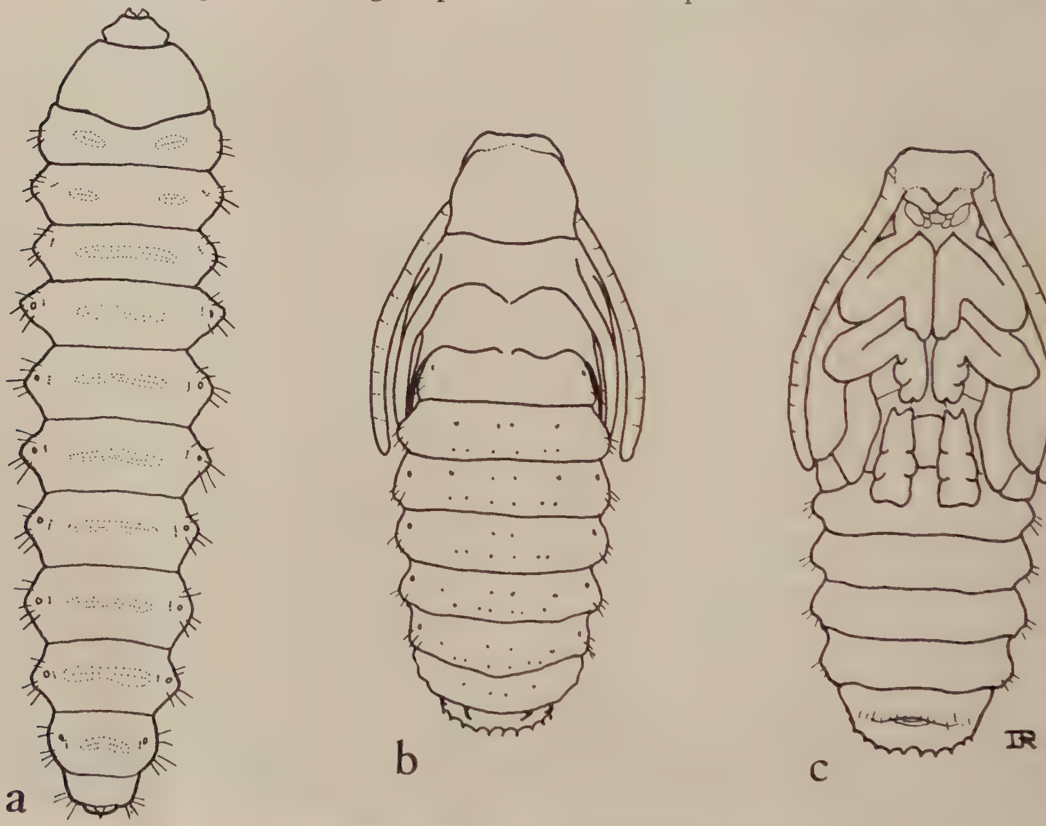


FIG. I.—*a, Larva, dorsal view; b, Pupa, dorsal view; c, Pupa, ventral view.*

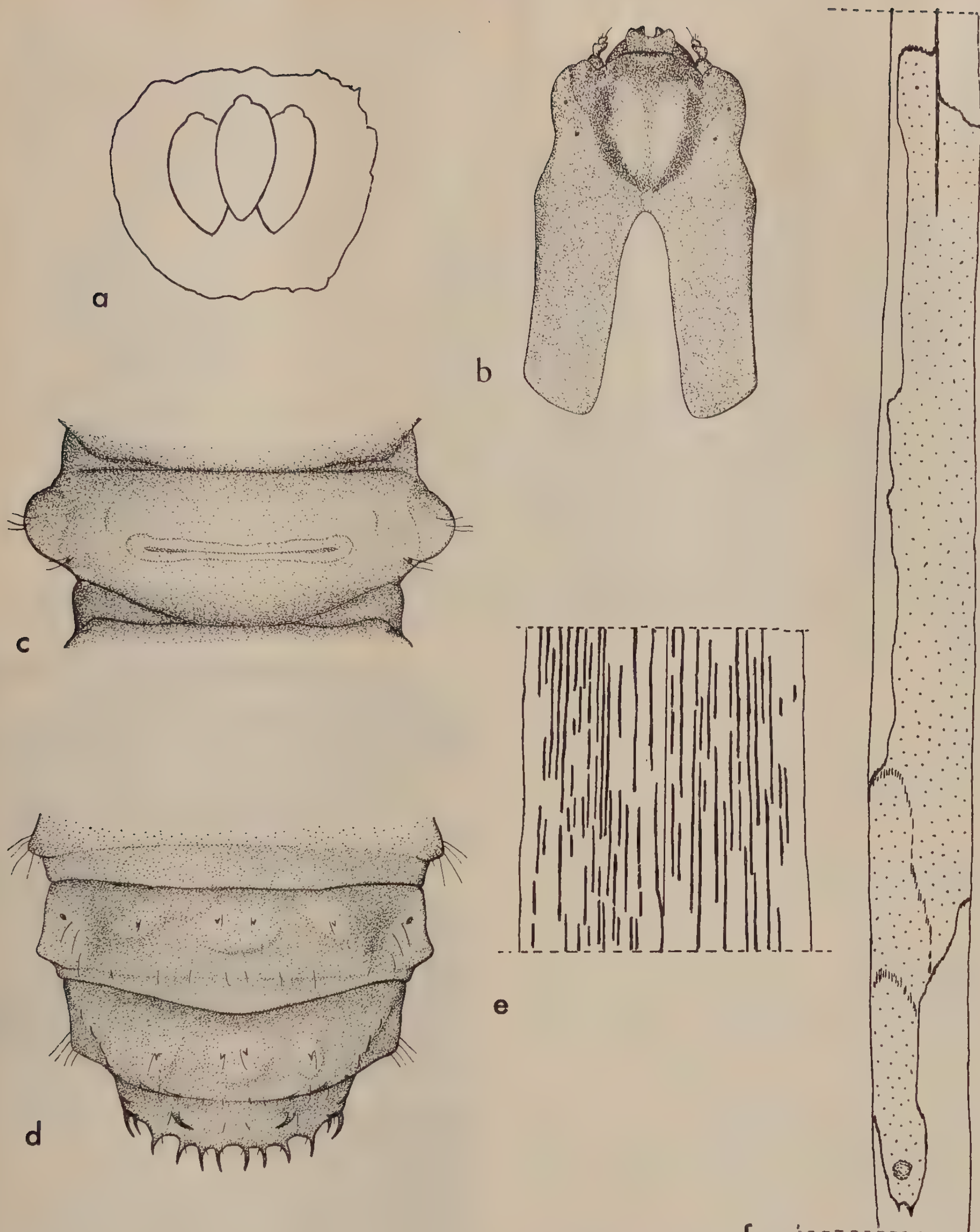


FIG. II.—*a, Ventral view of egg-case with 3 eggs; b, Dorsal view of head capsule of third instar larva; c, Dorsal surface of abdominal segment from middle of body of larva; d, Dorsal view of caudal end of pupa (mis-labelled larva in original publication); e, Adult feeding marks on underside of section of coconut leaflet; f, larval mine, from underside, on half of section of coconut leaflet, showing ootheca at bottom, and feeding areas of three larval instars; line at top is adult feeding scar. (Re-used from Gressitt, Nova Guinea, n. s., 8: 288).*

nature. Direction of mining is adjusted to accessible uneaten areas, and may be reversed Mines of moth leaf-miners are distinguished from beetle mines by having silk mixed with the excrement.

The principal beetle leaf-miners of palms of this region other than *Promecotheca* or other hispine beetles are small buprestid beetles, of which the larvae are more flattened and more elongated, with broadened thorax, and of which the adult beetles have shorter legs and antennae and a less constricted or less sculptured (never spiny) prothorax.

The average number of larvae per mine is three to five, correlating with numbers of eggs in the ootheca less eggs lost by parasitism or predation. However, during outbreaks, over-population may result in mines running together for lack of space. O'Connor once saw 13 larvae feeding abreast in a single mine. Under these conditions many cannot survive, for the area on one side of the midrib of a coconut leaflet cannot support more than about six or eight beetles to maturity. It is rare for larvae to mine through the midrib to the other side of a leaflet. At any rate, when one side is overpopulated, the other side is almost always likewise. As many as nine emergence holes were found in one leaflet at Vunakanau, but sometimes more than one beetle may emerge from one hole.

There are three larval instars, separated by resting and moulting periods. When the feeding period of one instar is completed, the larva recedes towards the middle of the mine, rests for two to three days, and then moults its skin, emerging from it with a larger new head capsule. Thus it is easy to recognize an instar by the size of its head capsule, which does not change its size as the body stretches during feeding in the course of one stadium.

Measurements of head capsules are :—

L_1 (1st instar)—0.54-0.6 x 0.78-0.84 mm.

L_2 (2nd instar)—0.72-0.81 x 1.28-1.40 mm.

L_3 (3rd instar)—1.15-1.30 x 1.95-2.05 mm.

Measurements of larvae :—

L_1—1.65-5.50 mm. (length).

L_2—5.5-7.5 mm.

L_3—7.0-13.2 mm.

Prepupa—12.0-13.0 mm.

The portions of the leaflet mined during each stadium are generally distinguishable by a darker pigmentation of the dry portion last fed upon by larvae of a particular instar. The green tissue here dries hard while the larvae are moulting, and at the start of the next instar the larvae first have to bite through this hard tissue. There is also often a slight shrinking of this area, and commonly a sudden widening of the mine just after the feeding of the larvae of the next instar has commenced. Lengths of mines are, first instar, 36-70 mm. ; 2nd instar 50-86 mm. ; 3rd instar, 84-394 mm. The larvae feed upside-down in the mines, with the dorsal surfaces of their bodies against the lower surfaces of the leaflets. The pupae are also in this position, the adults thus exiting through the upper surface. When removed from a mine, a larva arches its body backwards, with the ventral surface convex, in attempting to contact both upper and lower surfaces of a mine in order to move forward or backward.

PLATE 4.—*Mines with larvae* (*a*) *and adult feeding* (*b*) *on betel-nut palm, Vunakanau, May,* 1956.

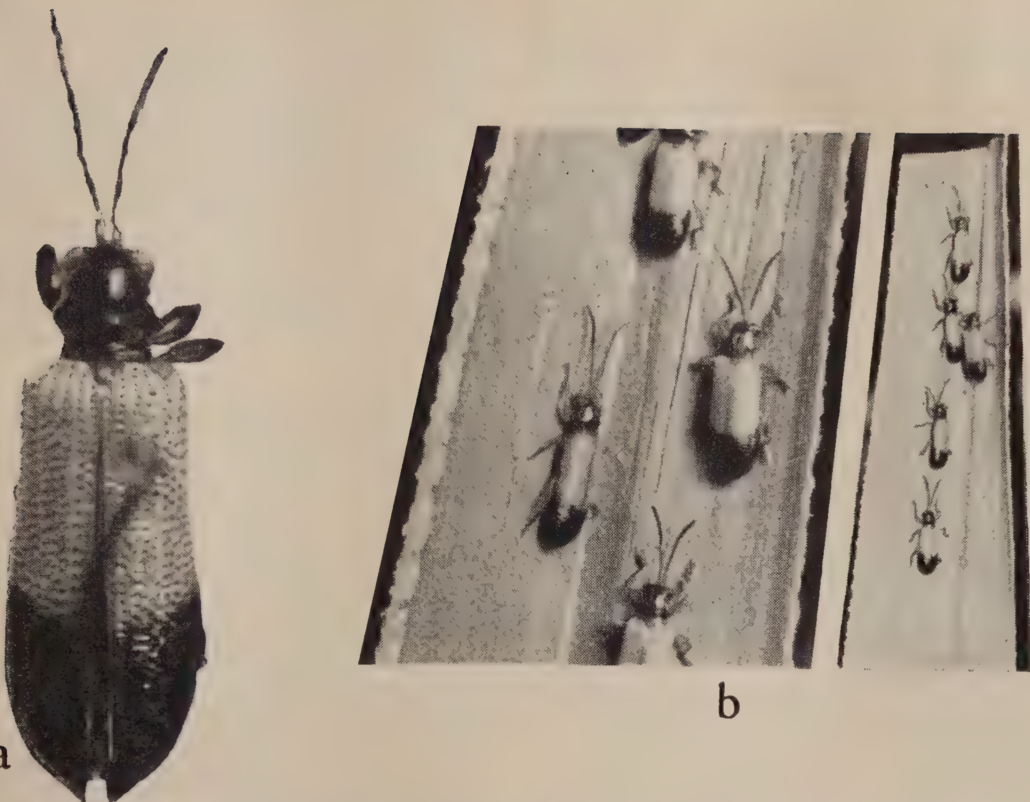


PLATE 5.—*a, Photograph of type specimen of Promecotheca papuana Csiki from Hungarian National Museum (Re-used from Gressitt, Nova Guinea, n.s.,* 8 : *pl.* 15 *f)* ; *b, Adults resting after feeding on coconut leaflets (in captivity).*

Prepupa

The full-fed third instar larva recedes in the mine and undergoes a quiescent period called the prepupal stage, of about three days. Early in this stage the body shrinks slightly in length and becomes more swollen and pinker, while the internal transformation to pupa commences.

Pupa

(Figs. I*b* and II*d*)

At the end of the prepupal period, the larval skin splits along the mid-dorsal line of the thorax, and the pupa works its way out by a series of convulsive movements. The old skin is pushed backwards and shrinks into a dry mass at the posterior end of the abdomen, later detaching and remaining free in the mine. The fresh pupa is pale creamy-white, but soon becomes golden brown. As development proceeds, the mandibles and eyes turn black, and then the wing pads darken, shortly before emergence of the adult. The dorsal surfaces of the abdominal segments are armed with bristles which permit locomotion by an arching and extension of the abdomen.

Technical description : Pale reddish brown, slightly darker on setal insertions, tubercles and spines. Head with about nine setae on each side ; pronotum with about five on each side of anterior portion and more than ten along side, with a few subbasal setae ; mesothorax with a few setae on middle of elytral pad ; sides of legs and abdominal segments each with several setae of varying lengths. Thoracic terga and first abdominal tergum smooth to slightly rugose ; second to seventh abdominal terga each with four distinct tubercles in a transverse line anterior to middle, the inner two more closely spaced, followed by a subtransverse row of minute tubercles consisting of insertions of small setae ; last abdominal tergite with a pair of inward curving spines and outer margin armed with

suberect slightly incurved spines. First five abdominal spiraches round, slightly projecting and tapering to opening; sixth similar but smaller; seventh vestigial, compressed. Abdominal sternites each with a postmedian transverse ridge bearing some setae, the insertions of which are larger and subtuberculiform on penultimate and antepenultimate segments. Length 8.5-10 mm.

Adult

(Plate 5)

On completion of the pupal stage the pupal skin splits down the back, and the adult emerges. At first it is pale, with some dark on posterior parts of elytra. It gradually hardens and becomes orange red with the head, prothorax, and ventral surfaces purplish-black and the posterior two-fifths of the elytra metallic blue to violet. Adults from Manus Island are paler than those from New Britain, and there is some variation in the proportion of blue on the hind parts of the elytra.

The new adult remains in the mine for about two days after emerging from the pupal stage. During this period it lies on its back, clutching the cast pupal skin with its feet. It then chews a crescentic slit through the upper surface of the leaflet. through which it emerges. The new adult generally flies away to another palm within a few minutes of emergence, and shortly afterwards starts to feed.

The adult beetles feed mainly on the undersurfaces of the palm leaflets, generally only on the terminal portions of terminal leaflets, unless the population is very dense. Sometimes the adults appear to prefer younger fronds and sometimes older fronds. They can feed upon both and when the population is at a high level they may go to the very nearest leaf shoot to feed. Since the adults are normally on the undersides of the pendant distal parts of leaflets, on the lower and middle fronds they are hidden from view from outside the crown, and are most easily seen on low palms by standing with back to the palm trunk and looking outward. It is easier to recognize the presence of the beetle by searching fronds with field glasses for evidence of mines or adult feeding. As shown below, there may be almost no adults present during part of the cycle of a "one-stage" epidemic.

The adults usually feed by facing upward with the body parallel to the leaflet. They turn their heads sideways to chew the surface by allowing the mandibles to penetrate between the main leaflet veins. This results in feeding marks consisting of straight narrow lines which turn brown and are visible from above or below. (Plates 1, 4.) When the beetles are abundant the entire ends, or entire leaflets, turn brown, and the whole palm may have a burned appearance. The damage caused by adult feeding is as extensive, or more so, as the damage by larval mining.

Copulation commences after a period of feeding lasting a few days, and is repeated frequently, sometimes daily over a period of two to three months. O'Connor noted copulation in captive beetles 135 days old. The copulating pairs appear to be gregarious. The females commence egg-laying 24 to 30 days after emergence, and may continue for some months if they survive that long. According to O'Connor the first eggs are laid seven to ten days after the first copulation, which he implied was more than two weeks after emergence. According to my observations, egg-laying commences at least two weeks after the first copulation, but the latter occurs just over a week after emergence. This is earlier than implied by O'Connor. After ovipositing for about a month, there is a resting period of about a month during which no eggs are laid.

The table of oviposition is after O'Connor.

The rate of egg-laying ranges between one ootheca every other day to two oothecae every three days and rarely one a day for a few days. One female at Vunakanau deposited five oothecae in one week. A female may lay at least 90 to 100 eggs, which is the equivalent of about 30 egg-cases at Manus and the Gazelle Peninsula and about 25 at Lindenhafen. Feeding, mating and oviposition take place only in the daytime, as far as known.

Sex ratio

Females are slightly more numerous than males. Of 500 reared adults, 217 were males and 283 were females, giving a ratio of about three males to four females. Of 179 collected adults, 84 were males and 95 were females, or

nearly eight males to nine females. The higher ratio of collected males to collected females, as compared with reared individuals, probably reflects the tendency for females to go higher in the palm crowns to oviposit particularly when population is dense and undamaged leaflets for oviposition become scarce.

Life Cycle

The life cycle occupies about two months from egg-laying to adult, and less than three months from egg-laying to first egg-laying. Thus there may be four to five generations a year. The cycle at Vunakanau appeared to be more rapid than this, so the above preoviposition period is probably too long, reflecting the effect of caging or disturbance of the cycle.

The egg stage at Vunakanau lasted from 12.5 to 15 days, with an average of 13.6 days. For Manus, O'Connor reported 13.5 to 16 days (average 15 days), and for Lindenhafen 13 to 15 days (average 14 days).

The larval stage lasts 17 to 30 days. The first stadium has a feeding period of eight days (five to nine at Manus), followed by a resting period, including the moult, of two to three days. The second stadium has a feeding period of 2.5 to five days (eight to 13 at Lindenhafen according to O'Connor), followed by a resting period of two to three days, including moult. The third stadium has a feeding period averaging four to eight days (four to 10 at Manus, six to 12 at Lindenhafen—O'Connor). The prepupal period lasts three days, rarely four, and the

TABLE I.—Oviposition

Adult emergence from mine	Preoviposition period	First oviposition period	Non-laying period	Second oviposition period
A. 10th February	28 days	10th March-6th April 27 days : 16 oothecae	32 days	8th May-22nd May 14 days : 4 oothecae
B. 14th February	28 days	14th March-15th April 32 days : 13 oothecae	42 days	27th May-27th June 31 days : 11 oothecae

TABLE II.—Larval and pupal development, in days.

	Manus Island				Lindenhafen Plantation					Vunakanau	
	Palms				Palms						
	Mature		Young		Mature		Young			Young Palms	
	B	C	D	G	H	K	a	b	c	d	e
First stadium—											
feeding	8	8	5	5	6	6	4	4	3	4	5
rest	2	3	2½	3	3	3	2	3	3	3	3
Second stadium—											
feeding	5	5	3	3	8	13	3	4	3	5	4
rest	3	3	2½	2½	2	3	2	2	3	2	2
Third stadium—											
feeding	10	10	7½	4	6	12	4	5	4	5	5½
To emergence of adult	15	15	15	15	15	15	15	14½	15	15	15
Total, egg-hatching to adult	43	44	35½	32½	40	52	30	32½	31	34	34½

NOTE.—Individuals B-K were observed by O'Connor while I observed A-E. H and K were reared by O'Connor in the laboratory in leaflets kept in water. The others were observed from day to day on living palms under plantation conditions. Columns a-e are partly composited of different individuals because of shortness of stays.

pupal stage lasts 9.5 to 10 days. Following metamorphosis the adult beetle remains in the mine for two or, rarely, three days before cutting its way out. O'Connor showed that larval development was more rapid in very long palms (see Table II).

However, the period of 15 days from the end of the feeding portion of the third stadium to emergence of the adult from the mine is fairly uniform, consisting of three days as a prepupa, 10 days, or slightly less, as a pupa, and two days as a resting adult in the mine before emergence. My Lindenhafen figures were completed by taking caged material and dated pupae with me to Vunakanau.

The adult beetle can live as long as five months, and probably longer, according to O'Connor. Of those he kept in captivity, none was kept until it died of natural causes. " They either escaped, or were still living when observations had to be discontinued ", O'Connor noted. " One female was kept at Lindenhafen for 160 days and a male and female for 140 days ".

In nature adults probably never live this long. Predation and diseases must exact a very great toll. Otherwise the one-stage condition could not be maintained, as discussed below.

Potential reproductive capacity

On theoretical figures, without consideration of parasites, predators, diseases and starvation of larvae through over-crowding, the progeny of a single female during one year could be 2,160,000,000. This is worked out on the arbitrary basis of four generations per year, 100 eggs per female, and a sex ratio of 60 per cent. females. Under circumstances of the one-stage condition the number of generations per year is probably at least five, because the life of most adults is cut short and the mean point of the egg-laying period is much earlier than in caged beetles. Thus the number of eggs is much reduced.

Since only up to about 15 adults can develop from one large leaflet, not more than 3,000 beetles could come from a large frond, and about 35,000 from one palm, allowing half the fronds for adult feeding space.

NATURE OF *Promecotheca* OUTBREAKS

Outbreaks of this beetle are peculiar in that they seem generally to be restricted to a particular plantation or limited area, or two or more isolated areas, at one time and tend to recur at intervals in these areas. Meanwhile, the beetle may exist under normal biological control in nearby areas. Localities in New Britain which are known to have had repeated serious outbreaks are the Linga Linga-Talasea area on the north-central coast, the Lindenhafen area on the opposite south coast, and parts of the Gazelle Peninsula. Many small outbreaks have occurred at other places, particularly along the north and south coasts of New Britain, in part correlated with main outbreaks and in part independent, and others have been reported from Manus Island and the Duke of York Islands.

TABLE III.—Life cycle, in days.

——	Manus	Lindenhafen		Vunakanau
Incubation period	15	14	14	13.6
Larval period (to end of feeding)	28	30	15	19
Prepupal period	3	3	3	3
Pupal period	10	10	9.5	10
Adult in mine	2	2	2	2
Adult to egg-laying	28	28	24	25
TOTALS	86	87	67.5	72.6

NOTE.—First two columns after O'Connor, the last two are mine. O'Connor's reared specimens were evidently delayed by adverse conditions.

If the life cycle is counted from egg-laying to middle of maximum egg-laying period, then a figure of about 50 should be substituted for the 28 above for adult to egg-laying. However, as pointed out above, in nature adult life is much shorter. Also, the figures 24 and 28, arrived at by O'Connor and myself in different ways, are probably too high. Thus there could be more than five generations per year.

The reasons that certain areas are more affected than others are not clear. Abnormally long, dry seasons have been associated in literature (Taylor, 1937) with the development of *Promecotheca* outbreaks in Fiji, principally through the build-up of populations of the mites *Pyemotes* ("*Pediculoides*") *ventricosus* which is said to destroy the parasites and contribute to the development of the "one-stage condition", through destruction of young stages of the beetle at a given time.

However, it is difficult to connect dry weather with the development of the New Britain outbreaks, because of the differences in rainfall and seasonal occurrence of rain in the areas most susceptible to the occurrence of outbreaks. Lindenhafen, where the worst outbreaks have been reported, has the highest recorded rainfall in the Territory of Papua and New Guinea, whereas the Gazelle Peninsula coconut areas have a much lower rainfall. It might be that the heavy rainfall at Lindenhafen is detrimental to the parasites when combined with some other factors. But the last outbreak at Vunakanau correlated with an extremely dry period. Only one fully-fed *Pyemotes* mite was seen during my study. This was at Lindenhafen. In 1953, Ardley reported many in frond samples sent from Lindenhafen, but found very few on his visit. There seems to be a general widely-spaced periodicity in the occurrence of *Promecotheca* outbreaks in New Britain. From the incomplete records, it appears that outbreaks may occur at intervals of approximately every 11 to 15 years or longer. In the Linga Linga-Talasea area outbreaks were reported in 1923, 1940 and 1954, and at Lindenhafen in 1937 and 1954. Constrictions at sub-equally-spaced wide intervals on the trunks of the mature palms planted during the German regime are quite noticeable over much of Linga Linga Plantation and on parts of Lindenhafen. The intervals between the constrictions correlate with the time periods between the known or rumoured beetle outbreaks. On many palms four distinct constrictions are visible, the highest being at the base of the crown (not yet visible in 1956 where old pendant fronds were still adhering), and representing the then just-terminated 1953-1954 outbreak (see Copeland, 1914, or Gressitt, 1953, for summary of chronology of palm crowns). Information obtained elsewhere, including Vunakanau, indicates a recurrence of outbreaks at similar intervals. Possibly when more climatological data are accumulated, some correlation may become evident.

The "one-stage condition"

The "one-stage condition" obtains in a population when there is a single cycle or generation progressing at one time—in other words, when the population in a given area consists entirely of one stage, or two successive stages (such as adults and eggs, eggs and young larvae, mature larvae and pupae, or pupae and adults) at a given time. The one-stage condition seems to be characteristic of outbreaks in New Britain.

The main factors contributing to the development of the "one-stage condition" have not been determined. No concrete evidence has been demonstrated that it is caused by build-up of the harvest mite *Pyemotes* ("*Pediculoides*") *ventricosus,* as was proven in Fiji, although this mite is present in New Britain. It seems suggestive that some major upset of the parasite balance must take place, for the "one-stage condition" seems to be inseparably linked with the occurrence of outbreaks. For the development of such high populations as exist in outbreaks, the parasites must be rendered ineffective for a period.

Possibly the beetle population increases rapidly after mortality of certain stages has produced the "one-stage condition". The parasites then lack suitable host material for oviposition, as the life-cycle of the parasites is shorter than that of the beetle. Many beetle generations are apparently required before the parasites can gain the upper hand again and reduce the beetle population materially.

Once the "one-stage condition" is attained, it seems to be maintained for a long period—often up to two years. This seems to contradict knowledge of the egg-laying period of the female beetle, which theoretically should permit termination of the "one-stage condition" within a generation or two. However, my observations confirm O'Connor's suggestion that the adult population decreases much more rapidly than would be expected from the observed adult life-span and oviposition period in captivity.

Predators and diseases are probably mainly responsible for this rapid decline in adult population [very clearly observed at Vunakanau; see diagrammatic graph (Fig. III)]. At the same time, the smaller number of eggs and larvae resulting from the small number of adults carrying over between one peak in adult population and the next, is undoubtedly completely parasitized by the parasites avidly searching for host material during the period of dearth between the peaks in larval population of two successive generations. Thus, between the predators and the parasites, the "one-stage condition" is perpetuated, to the continued disadvantage of the parasites. From the standpoint of the predators, the food supply (of course not an obligatory relationship) is irregular, particularly for those feeding only upon one stage of the beetle. O'Connor noted that the "one-stage condition" persisted during his eight-month study at Lindenhafen, which was two years after the outbreak started.

Further studies are required to prove whether the responsibility for the inception of the "one-stage condition" in New Britain lies with the mite *Pyemotes* or with some other factors. It also seems suggestive that climatic aberration is in some way involved. For several months preceding the discovery of the outbreak at Vunakanau at the end of 1955, the immediate area had suffered an unusually long period of drought.

The reason why the *Pediobius* ("*Pleuro tropis*") parasite was so successful in Fiji, and much less so in New Britain, remains uncertain. The life-cycle of the New Britain *Promecotheca* is, however, slightly shorter than that of the Fiji species. Possibly some factors obtaining as a result of climatic cycles prove unfavourable to the *Pediobius*. The native parasite *Apleurotropis* ("*Derostenus*") definitely competes with *Pediobius*, and can win out over it when eggs of both are laid in the same mine. At Linga Linga the former was found to be more abundant than the introduced parasite in 1956. However, *Pediobius* is often more abundant than *Apleurotropis* in various parts of New Britain.

One interesting fact is that the beetle is often scarce in coconut plantings on off-shore islets near Linga Linga and Lindenhafen during outbreaks at these plantations.

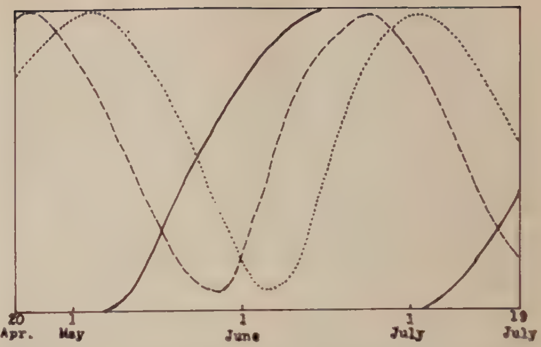


FIG. III.—*Diagrammatic graph showing a "one-stage condition" of generations of beetle at Vunakanau Plantation, Gazelle Peninsula,* 1956.

- - - - - - - Adults :—

Top of graph represents 200 or more adults per frond.

——— Mines :—

Top of graph represents completion of development, with complete area of majority of leaflets on older fronds mined, leaving no green tissue.

. . . . Eggs :—

Number newly laid. Top of graph represents superoviposition on new fronds or remaining green tissue: up to 30 or more egg-cases per leaflet, which is many times the population which could develop from available food for larvae.

PARASITES

Much of this section is repeated from O'Connor's report (1940), as, during most of my period of study, hosts were extremely rare (Linga Linga in particular), or in the adult-egg-early larval phases of the "one-stage condition" (Vunakanau, Taliligap).

Pediobius parvulus (Ferriere).

This eulophid wasp, known in earlier *Promecotheca* reports as *Pleurotropis parvulus*, was introduced from Java to Fiji, and later to the New Hebrides, to control other species of *Promecotheca* and was outstandingly successful, particularly in Fiji where it is now difficult to find *Promecotheca* on the main island. In October, 1938, a colony of this wasp was received in Rabaul with the co-operation of R. J. A. W. Lever (1938), and Messrs. W. R. Carpenter & Co., Ltd. The parasites were bred up in Rabaul and distributed in the Rabaul district, Manus Island, Talasea, Pondo and other localities.

At the end of November, 1938, O'Connor was sent with a colony to Lindenhafen, where *P. papuana* was present in very large numbers

at the time. Breeding and distribution of the parasite was carried on in the district until the end of July, 1939, by which time *P. parvulus* was firmly established at Lindenhafen. Daily collection of *Promecotheca* was carried out, so that a check could be kept on the progress of the parasites in the field. O'Connor found that two weeks after the initial liberations, parasitized larvae and pupae could be found on the site of liberation, and even as much as 200 yards away from this point. A gradual increase was discernible in percentage of parasitism in the field as shown by the figures below. Percentages were based only on mines which contained healthy larvae, pupae, or adults of *Promecotheca,* or larvae and pupae containing *P. parvulus,* all those from which *P. papuana* or *P. parvulus* had emerged being excluded.

TABLE IV.—Parasitism by *P. parvulus* at Lindenhafen six months after release (O'Connor).

	Total Mines.	Mines containing parasitized individ.	Per cent. of mines containing parasitized individuals.
6th-22nd June, 1939	414	18	4.3
23rd-30th June, 1939	451	10	2.2
1st-14th July, 1939	872	33	3.8

Incomplete counts for the latter half of July indicated that the parasitism had jumped suddenly to about seven per cent. In October, 1939, counts of mines sent to Rabaul from Lindenhafen showed a 50 per cent. parasitism.

In the Rabaul District, possibly due to the generally drier and finer weather, *P. parvulus* seemed to have multiplied much more rapidly than at Lindenhafen. Most of the liberations around Rabaul and Kokopo were made early in 1939, and by August parasitized larvae and pupae could be found in numbers by casual inspection. At Wangaramut Plantation, for instance, between 200 and 300 mines were opened, and every one of these contained one or more parasitized larvae and pupae. Other plantations on which the parasites were by then well established were Ralabang, Ulatava, Keravat and Pondo, showing that their spread was rapid and wide.

In 1954 Ardley reported that *Pediobius* had re-established itself after the outbreaks at Linga Linga and Lindenhafen. He demonstrated a parasitism of 47.1 per cent. at Linga Linga, and noted 90 per cent. parasitism by *P. parvulus* on Boronga Island, just off Lindenhafen.

In 1956 I found low populations of both hosts and parasites at Linga Linga, where *Pediobius* was less abundant than *Apleurotropis* ("*Derostenus*"). Total larval parasitism appeared to be 13.3 per cent. At Lindenhafen it was 28 per cent., apparently all *Pediobius.* At Vunakanau, larval parasitism varied, going quite high, and consisting mostly of *Pediobius* (see Table V). In old mines it often proved to be at least 90 per cent.

Method of breeding

A satisfactory method for bulk breeding is as follows : Into a large mine, from 20 to 40 prepupae, or nearly-formed beetle pupae, are placed. The ends of the mine are cut and closed with wire clips, and the mine is then placed in a glass tube about eight inches by an inch and a half with 100 to 200 *P. parvulus* (i.e., five wasps per beetle) and left for two days. Food is provided in the form of honey very slightly diluted with water, which can be placed on a small piece of blotting paper stuck to the side of the tube, or on the upper surface of the mine in very small droplets.

At the end of two days, the prepupae and pupae are removed, and stored in a glass tube six inches by one inch.

If the climate is moist, the tube should be lined with blotting paper, and adult beetles emerging from unparasitized pupae should be removed daily, otherwise there is a risk of sweating, and consequent fungus attack on the parasitized individuals. The same individuals of *P. parvulus* can be used three or four times for oviposition in fresh lots of *Promecotheca.* Prepupae and pupae are preferred to larvae, as the latter have to be fed before and after parasitism, a process which occupies a great deal of time.

These methods were used at Lindenhafen, and produced from 1,000 to 1,500 well-grown wasps per day. Superparasitism was found to be negligible. The developmental period of *P. parvulus* from parasitism to emergence of wasps was found to be 16 days in Rabaul and 19 days at Lindenhafen, the difference being due to higher mean temperatures at Rabaul.

TABLE V.—Parasitism of immature stages, New Britain, 1954, 1956 and 1957.

——	Egg parasitism : " Closterocerus splendens "		Larval-pupal parasitism : " Pediobius parvulus " (unless otherwise noted)		
Data	Total oothecae	Per cent. parasitism	Larvae-pupae	Per cent. parasitism	Aborted mines
1954—					
Linga Linga (Ardley)			1,665	47.1	....
1956—					
Iboki (nipa palm ; Ardley), April	21	92	....	....	....
Linga Linga (*Apleurotropis, Pediobius* and *Eurytoma*), April	....		60	13.3	
Volupai, April			55 mines	95	40
Lindenhafen, April	151	58	129 mines	28	12
	177	24	32 mines	30	
Vunakanau :					
20th April (Ardley)	575 (old)	16.5	249	80.7	
5th May	362 (new)	7	233 mines (old)	25	32
	...		214 mines (old)	59	
15th May	40	86	....	....	
21st May	687	38	....	....	5
23rd May	809	63	....	....	
4th July	362 (old)	54	146	67	16
19th July	43	54	....	....	
1957—					
Vunakanau :					
10th October	56	55	...	....	
1956—					
Taliligap :					
25th May	244	49	....	....	
29th May	310	50	....	....	18
4th July	47	72	116	70	19

In this connection, it was calculated by O'Connor that the developmental zero for *P. parvulus* was approximately 55 degrees F. (12.8 degrees C.). To determine this figure, parasitized *P. papuana* were kept in a refrigerator and in the laboratory, and development of *P. parvulus* noted while taking temperatures at three-hourly intervals.

Description

The adult wasp is black, robust, about 1.6 mm. in length. The three proximal tarsal segments on each leg are white, the fourth segment, like the tibia and femur, being black. Males are smaller than females, and have a greenish sheen on the ventral portion of the thorax. The larva is white, slender, and tapering at each end.

Bionomics

The egg of the wasp is laid, from outside the mine, into the larva, prepupa or pupa of *Promecotheca*, the ovipositor of the female wasp penetrating the epidermis of the leaflet to reach the host. Oviposition is usually carried on from the under surface of the leaflet. Where the host is a well-grown, third-instar larva, a prepupa or a pupa, the developmental period of the parasite is shorter than when a first-instar or second-instar larva is the host. At Lindenhafen, 19 to 21 days was the usual period, but some individuals occupied as much as 27 days even in large third-instar larvae. In the second-instar larvae, the period was 21 to 23 days, with some individuals occupying up to 30 days. At Rabaul, 17 to 19 days was the usual period when large larvae were the hosts. When the life cycle covered 19 days, the larval period was about eight to nine days, and the pupal period 10 to 11 days.

The pupae, when first formed, are white, but darken quickly, until they finally become quite black. The skin of the host turns black about

six or seven days after oviposition, in the case of third-instar larvae. When prepupae are attacked by the parasite, they almost invariably reach the pupal stage before dying and the pupa turns greyish brown, not black. Parasitized larvae always feed more voraciously after eggs of the parasite have been laid in them and in the case of first- or second-instar larvae, the subsequent feeding period may be as long as 14 days. Feeding by the parasite larvae goes on entirely within the host and when the prepupae form the pupae are packed inside the dried larval or pupal skin.

When fully developed, the adult parasites cut holes in the dry skin of the host, and emerge into the mine, where they then cut holes in the upper epidermis of the leaflet, and escape. If the portion of the host skin in which the hole is made is pressed against the epidermis, the parasites bite their way directly out, and do not enter the body of the mine. The number of holes made in host and mine varies from one to six.

Superparasitism

This has seldom been observed in nature, but in laboratory breeding, when parasites are placed in a tube with an insufficient number of hosts, it is of common occurrence. If the degree of superparasitism is moderate, the parasites complete their development, but emerge as stunted adults. If it is extreme, development is not completed, parasite larvae and host shrivelling up completely. In one shrivelled third-instar larva, 180 *P. parvulus* larvae were counted. It appears that up to 40 good-sized wasps can develop in a prepupa, pupa or mature larva.

Eurytoma promecothecae Ferriere

This parasite was described (1939) from specimens collected in the Rabaul and Lindenhafen areas. It is a black wasp, about 3 mm. in body length, with the distal ends of the tibiae yellow, and the tarsi white. The antennae of the male differ from those of the female, the funicle segments of the male being hairy and irregular in shape, while those of the female are smooth and rounded. This species has been recorded only from New Britain, and it appeared to be the main factor in controlling the outbreak of *P. papuana* which occurred along the north coast road in the Rabaul District subsequent to the volcanic eruption of May, 1937. It would appear that the outbreak was due largely to destruction of many of the local parasites by the deposits of ash which fell on the plantations in this area, followed by torrential downpours of rain. It was noticeable that those plantations which had suffered most from the ash and the cloudbursts were subsequently the most severely attacked by *Promecotheca.*

E. promecothecae is an external parasite of the larva of *P. papuana,* each of the three instars being attacked. The parasite larvae are voracious feeders and, attaching themselves to the sides of the host larva, they suck its body fluids. Feeding is especially heavy during the last day, when the host larva shrinks from almost normal size to a shrivelled husk. The host larvae are paralysed by the adult wasp when the latter lays its eggs and are unable to rid themselves of the parasite larvae.

When the larva of the parasite is fully fed, it moves along the mine and pupates, the pupa being attached to the wall of the mine by a drop of excreta and the cast larval skin. Its colour is at first pale yellow, later becoming black. The developmental period, from oviposition to emergence of the adult wasp, is 19 to 21 days at Lindenhafen and 17 to 20 days at Rabaul. The adult cuts a hole in the epidermis of the leaflet, usually on the upper surface, and emerges. Maximum longevity of adults in the laboratory was 60 days when not provided with hosts and 35 days when permitted to oviposit into larvae.

Apleurotropis lalori Girault ("*Derostenus* sp.")

This parasite (Girault, 1938) of the larvae of *P. papuana* occurs widely throughout the Territory, having been recorded from Lindenhafen, Rabaul and Manus. It belongs to the family Eulophidae. The adult is of a metallic-green colour, with coxae, tibiae and tarsi of all three pairs of legs white. Body length is about 1.6 mm. The adult has a very characteristic habit of running rapidly sideways and of standing on the leaf swaying its body to and fro.

This insect is an internal parasite of the larva of *P. papuana.* The host does not feed after oviposition by the parasite, and the parasite larvae develop inside the body of the host, which gradually assumes the appearance of the transparent envelope enclosing the parasite larvae. When fully fed, these latter bite their way out of the skin, and pupate in the mine, the pupae being attached to the walls of the mine by a drop of excreta and the cast larval skin. The skin of the host remains distended and trans-

parent. The parasite pupae gradually become black in colour, and normally the adults emerge and bite their way out of the mine 18 to 21 days after oviposition by the parent generation. Larval and pupal periods at Lindenhafen were approximately equal. At Linga Linga the prepupal stage was three days and the pupal stage eight to nine days.

In the laboratory, *Apleurotropis* failed to oviposit in prepupae and pupae and no larvae parasitized by it ever reached the pupal stage. However, in the field it was not uncommon to find pupae parasitized by this species, their appearance being very similar to that of pupae attacked by *P. parvulus.* Three adult females, supplied regularly with food and host larvae for oviposition, lived 25, 26 and 32 days in the laboratory, laying eggs until a day or two before death. When *Apleurotropis* and *P. parvulus* females were allowed to oviposit into a host larva at the same time, *Apleurotropis* always won in the competition for food and only *Apleurotropis* adults later emerged from the parasitized larvae.

Closterocerus splendens Kowalski

This eulophid wasp is just over 1 mm. long, with brilliant metallic-green body and banded wings. It was originally described by Kowalski (1917) from the New Hebrides as a parasite of the larva of *Promecotheca opacicollis* Gestro, but in the Bismarcks, where it has been found in the Manus, Rabaul and Kandrian (Gasmata) districts, it is an egg-parasite. The bionomics of this species have not been extensively studied, but the developmental period from egg-laying to emergence of adult is about 21 days or less. One parasite develops in an egg of *P. papuana* and an ootheca may have one or more parasitized eggs. When the parasite is fully developed, it cuts a small hole through the covering of the egg case, through which it emerges.

C. splendens, and to a lesser degree the egg parasite *Anastatus* sp., are believed to be the main factors causing the break in overlapping of generations in the Lindenhafen and Rabaul areas. At the beginning of egg-laying in one generation of the beetle at Lindenhafen, an attempt was made to estimate the percentage of parasitism of the eggs at different periods. Egg cases were collected from widely separated portions of the plantation, and the leaflets on which they were laid were kept in water for 10 days to allow any parasites which might be in the eggs to develop to a point where they were easily distinguishable. Laying of eggs in the field by this generation of beetles began about 20th May, 1938, and hatching of parasites from these eggs began about 9th June. Results of the examinations of eggs collected at three different times are :—

6th June, 1938—30 per cent. of eggs parasitized.

20th June, 1938—80 per cent. of eggs parasitized.

3rd July, 1938—100 per cent. of eggs parasitized.

Hence we see that about six weeks after egg-laying began 100 per cent. of the eggs were parasitized, and this could explain the restriction of overlapping of generations to about that period.

In 1956 I followed some of the above steps taken by O'Connor, mainly at Vunakanau. My results are not quite as striking as his, but an increase in parasitism was clearly noted. My figures are shown in Table V.

Anastatus sp.

This encyrtid wasp is about the same size as *C. splendens,* and is of a brilliant blue-black colour. It has been reared from the eggs of *P. papuana* in the Manus and Lindenhafen areas.

Achrysocharella orientalis Ferriere

This species is apparently a hyperparasite, and therefore not beneficial. It was described (1933) from a *Promecotheca* from Java, taken by R. W. Paine. One was reared from a *P. papuana* larva at Lindenhafen, and another was taken on a first-instar larval mine at Vunakanau, both by me in 1956. This apparently constitutes a new record for New Britain (Burks identification).

Other internal parasites

One other parasite of the larva of *P. papuana,* whose habits are similar to those of *P. parvulus,* has been found in Manus by O'Connor. Two species of minute hyperparasites were found by O'Connor, one in Manus and one at Rabaul, both reared from the egg parasite *C. splendens.* I noted a possible dipteran parasite, but this was not adequately verified.

RELATIONSHIPS WITH ANTS

From my study it has become apparent that ants are of the greatest importance in relation to the population balance of *Promecotheca,* more

so than earlier believed. Several species have been observed as predators, particularly of eggs of the beetle. Others are also larval or even adult predators, and at least one species is detrimental from the standpoint of preventing invasion by other ants useful in controlling the beetle.

Oecophylla smaragdina (Fabricius), (*the "Kurukum"*)

This ant has a very definite adverse relationship towards *Promecotheca.* There is fairly-general (often very distinct) correlation between the presence of kurukums and the absence of *Promecotheca.* This was observed repeatedly when searching for *Promecotheca* at Linga Linga and Lindenhafen. In May, 1954, Ardley correlated presence of kurukum ants on palm trunks at Linga Linga with palms not seriously affected, when nearly all other palms were badly affected (see Table VI) and this was further verified by Ardley and myself at Linga Linga in 1956.

At Vunakanau, where the area east of the manager's house in general was very badly affected to the extent of complete browning of all but the newly-emerging fronds, a number of palms were green and almost unaffected by the beetle. Of one group of six adjoining palms, all of which were green, four had kurukums in numbers going up and down the trunks. The other two were climbed and proved to be swarming with Kurukums. A few days later kurukums were noted on the trunks of these two palms also. The crowns of these palms were partly in contact, and presence of large numbers of kurukums in a palm crown cannot always be ascertained by merely examining the trunk.

Of another nearby group of five palms, which were largely green, all had numbers of kurukums running up and down the trunks or into a large cacao tree with leaves touching the trunks.

These cases, and those observed by Ardley, all involved mature palms. In the case of young palms, the correlation is not always so distinct. This I believe to be at least in part a result of the fact that kurukums observed in young palms may be there transitorily, or may have just recently established colonies and not yet evicted the *Promecotheca.* Small populations of kurukums obviously have a lesser effect on the occurrence of the beetle in palms.

TABLE VI.—Relationship of *Oecophylla* (kurukum) to *Promecotheca* damage, Linga Linga (after Ardley).

ANALYSIS OF 1,000 PALM SAMPLES, BASED ON TRANSECT TOTALS, MAY, 1954

Category	Degree of damage	Per cent. of palms	Per cent. of palms with kurukums
1	Palms unattacked by *Promecotheca*; full crown; full production; flowers to mature nuts	10.8	97.5
2	Palms partly damaged; full crown; 50 per cent. clean fronds; full production; flowers to mature nuts; production could be maintained if *Promecotheca* controlled	13.3	61.4
3	Palms severely damaged; full crown; 25 per cent. clean fronds; 75 per cent. production; flowers to mature nuts, but nuts will fall to nil	12.5	63.7
4	Palms partly defoliated; 50 per cent. crown; 25 per cent. clean fronds; 10 per cent. production, will fall to nil	19.2	30.4
5	Same as (4), but no nuts remaining	9.6	27.3
6	Palms more defoliated; 40 per cent. crown; 20 per cent. clean fronds; no nuts or flowers	17.0	17.1
7	Same as (6) but with signs of re-attack by *Promecotheca* on green fronds	1.7	0.0
8	Replantings and omissions	15.9	
		100.00	

NOTE.—It should be emphasized that the outbreak at Linga Linga was about over when Ardley's survey was made, and most of the palms contained no active *Promecotheca.* Thus the kurukums could have moved after the beetles were active.

Stanley (1938) failed to observe kurukums attacking beetles in infested palms, and O'Connor stated that he observed large numbers of kurukums passing along frond midribs while *Promecotheca* adults fed or oviposited undisturbed on the leaflets. I believe that such cases occur when the kurukums are migrating, or when they are busily engaged in tackling some major problem and are not carrying out general foraging. My data showing how seldom kurukums and *Promecotheca* are found in the same palms are presented in Table VII.

TABLE VII.—Relationship of *Oecophylla* (kurukum) to *Promecotheca*. 1956.

Plantation	Number of palms checked		Palms with............			
	Total	Young palms	Neither Promecotheca nor Oecophylla	Promecotheca, but no Oecophylla	Oecophylla, but no Promecotheca	Both Promecotheca and Oecophylla
Linga Linga	212	66	66	120	26*	0
Volupai	82	81	7	70	5	0
Lindenhafen	106	58	3	91	5	7*
Vunakanau	153	79	4	125	22	4

* The figures in next to last column include some cases where kurukums were present in palms with old adult *Promecotheca* feeding marks, or in a few cases with beetle eggs. The figures in last column in most cases represent palms with very few kurukums present.

Few positive observations have been made of kurukum predation upon *Promecotheca* yet the indirect evidence is strong and tests made in the field seem to add weight to these conclusions. In one instance, most of the egg cases, numbering hundreds, on a new frond of a young palm at Vunakanau were observed to be disappearing while under daily observation. Some new kurukum nests had just been established between a series of leaflets of the same frond. It is well recognized that few insects occur in numbers where kurukums are abundant.

Tests were made of reactions of kurukums to *Promecotheca* by releasing adult beetles on a coconut frond midrib, or near the bases of leaflets, where kurukums were going to and fro. Some of the beetles took immediate flight and escaped to a part of the palm lacking kurukums, while others flew into the presence of other kurukums and were caught and the remainder was caught by the ants before they could take flight. Several were caught by an antenna or leg by a single kurukum and held till other ants seized the other appendages. Then the beetle was simply held with its appendages stretched in all directions until it died. In one case the antennae were pulled with unequal force (Plate 6) so that the head was pulled off and promptly carried off while other ants later carried the body away.

I believe that kurukums both catch and chase away adult beetles, preventing them from laying many eggs in a palm well populated with the ants. They also chew away eggs when the ants invade beetle-inhabited palms. This ant is well known for its belligerency and will attack almost any invader. Once at Vunakanau I observed a large number of kurukums holding a dead rat on the midrib of a young palm. The rat remained there for several days, constantly held by many ants, as it gradually dwindled in size from being fed upon.

Kurukums were found at Linga Linga in palms of all conditions, from healthy to storm-felled, except for some of the very young or very unhealthy palms.

Monomorium floricola Jerdon

This minute, slender, black ant was several times observed singly or in small groups to be chewing in *Promecotheca* egg-cases. The cases, which were frequently found with small irregularly-chewed holes, were thought to be mainly the result of predation by this ant. *M. minutum* Mayr, *M. floricola*, and *Tetramorium guineense* Fabr. were reported by Froggatt and O'Connor (1941) to attack larvae in mines.

Technomyrmex albipes (Fr. Smith)

This very abundant, medium-small black ant was commonly found in palms infested by *Promecotheca*. It is probably one of the most important predators of *Promecotheca* eggs, and possibly also of the larvae. It may be the ant recorded by O'Connor as *T. detorquens* Walker.

Polyrhachis rastellata and P. sp.

These two large ants, shiny black and silvery grey-black respectively are often found in palms infested with *Promecotheca,* the ants making small nests of debris and silk on undersides of leaflets. Though insufficient positive observations were made, these may be predators of some importance. They are active and fairly belligerent ants. The latter species was particularly abundant at Linga Linga.

Camponotus papua Emery

These moderately large, shiny, reddish-brown ants, common in New Britain, are frequently found in coconut crowns, often nesting at the bases of leaflets. They are also thought to be *Promecotheca* predators.

Tapinoma melanocephalum Fabr.

This species was reported by Froggatt and O'Connor (1941) to attack larvae in mines.

Pheidole megacephala Fabr.

This medium-small, black ant was reported by Froggatt and O'Connor as being the most important local ant predator of larvae in mines. It also attacks the egg-cases, although I did not see as many as other workers have mentioned.

Cremastogaster sp.

This slender pale ant was occasionally found near *Promecotheca* egg-cases or mines, and is believed to be a minor predator.

The combined effect of predators, mostly ants, on egg-cases is shown in Table VIII.

Iridomyrmex aff. myrmecodiae

This small, reddish ant, a fierce biter, is common in coconut plantations. It builds long, slender nests of the grass-like pubescence on new palm petioles. The nests are often on the new leaf-shoots, or along the frond midribs. This ant is generally represented by large populations localized in certain palms and is often in the minority in New Britain. When *Iridomyrmex* is present, other ants are generally not found in the same palm.

The presence of *Iridomyrmex* does not seem greatly to affect the prevalence of *Promecotheca.* If this ant is not a predator of *Promecotheca* eggs or larvae, as are several of the common ants in the coconut plantations, then it is definitely not beneficial from the plantation standpoint, as far as *Promecotheca* is concerned, for it deters other ants, which are predators. *Iridomyrmex* is common in other palms, particularly on the

PLATE 6.—*Kurukum ants (Oecophylla) decapitating an adult beetle.*

TABLE VIII.—Predation upon oothecae and mines of *Promecotheca*

Data	Oothecae (egg cases)		Mines	
	Number sampled	Per cent. predated (mostly by ants)	Mines predated	Agent
Vunakanau—				
14th May, 1956	135	33.3	6	earwig
14th May, 1956	385	57.1	22	miscellaneous
15th May, 1956 ...	1,100	42.0	5	birds
19th May, 1956 ...	250	40.0		
21st May, 1956	260	39.2		
22nd May, 1956	785	14.6		
26th May, 1956	157	7.0	2	?
19th July, 1956 ...	125	23.2	1	bird
Taliligap—				
16th May, 1956	371	34.2		
4th July, 1956 ...	80	27.5	3	?
Volupai—				
16th April, 1956			2	parrot
Lindenhafen—				
25th April, 1956			3	birds ?

NOTE.—In some cases new eggs were examined, and a more extended observation would have given higher counts of predation.

new leaf shoots. This ant in Bougainville and the British Solomons is responsible for coconut nutfall by deterring other ants, particularly the kurukum, which in turn deters the *Amblypelta* bugs, which cause the nutfall.

OTHER PREDATORS

Vertebrates

I believe the importance of vertebrate predators upon *Promecotheca* has been overlooked in New Britain. Various lizards, particularly skinks, and also geckos and others are abundant in the plantations, and those frequently seen in the crowns undoubtedly feed upon the adult beetles. Several lizards kept in captivity at Vunakanau fed upon adult beetles. Taylor (1937) reasoned that in Fiji mines were observed to be torn open with the larvae removed were the result of predation by a species of lizard, but similarly ravaged mines in New Britain I believe are at least partly the result of feeding by birds, probably parrots.

It was noted that at Linga Linga and Lindenhafen the malip parrot (*Domicella* sp.) was exceedingly abundant, whereas it was absent, or nearly so, from the Vunakanau area. At Volupai a pet malip tore open some mature larval mines I was observing, apparently eating the larvae. The marks left by this action—a doubt slit in the dorsal surface of the mine—were identical with those observed a number of times in central New Britain. Marks of this nature were seldom found at Vunakanau. Possibly some other birds may also be of importance as predators of the beetle.

Earwigs

Frequently, in examining old mines, living or dead earwigs were found inside. They had entered through roughly chewed, rounded holes on the undersides of the mines, quite different from the clean-cut crescentic dorsal emergence holes of the adult beetles. No observations were made that prove that the earwigs are actual predators upon larvae or pupae and they may be mainly scavengers. However, O'Connor believed they were predators, and this is probably true. The same earwig is a known predator upon larvae and pupae of *Brontispa*. One adult earwig, confined with an adult *Promecotheca*, killed the beetle. Another may also have done so, though it first killed a young earwig in the same container. It is unlikely that earwigs often feed upon adult beetles, except possibly females ovipositing within a newly unfolding leaflet or in mines before emergence. An earwig catches living prey by seizing it with its caudal forceps and then chewing it while still holding it with the pincers.

Miscellaneous predators

A predatory pentatomid-bug, *Amyotea reciprocus*, was noted by Simmonds (1924) and

others as a predator of adult beetles, but I did not observe it. A predaceous pyrrhocorid-bug, not yet identified, appears to be a general predator of adult insects (and also of snails) in this region, but it is more often found around logs and trunks of trees. One was seen feeding upon a cacao capsid. A fly of the genus *Drapetis* (Empididae) appeared to be sucking the body fluid of a first-instar *Promecotheca* larva through the epidermis, at Vunakanau. Another small fly, possibly a heleid, appeared to be feeding on an adult beetle. Dragon-flies undoubtedly catch some adults flying around palm crowns.

Mites

A trombidiiform mite, possibly a predator, was found in an ootheca. Mesostigmatid mites were found on adult beetles, but are probably of no particular harm unless occurring in large numbers. Oribatid and pterogasterine mites found in mines were probably scavengers or fungus feeders. *Pyemotes,* as discussed above, was rare.

Diseases

As noted by O'Connor, there are fungal, bacterial, and perhaps other diseases of larval or adult beetles. It is possible that a virus or other disease of the adult beetle may be partly responsible for the rapid diminution in adult populations during high population one-stage outbreaks. A disease of this nature becoming prevalent only at such times, however, would probably tend to maintain the one-stage condition, rather than reduce damage to palms. Under high population conditions the elimination of even a very high percentage of the adults will not greatly reduce the population of the next generation, as long as a small proportion of the eggs laid can develop to maturity. A fungus, *Synnematium jonesii,* is reported as attacking larvae in the mines (Lepesme, 1947).

ARTIFICIAL CONTROL MEASURES

No truly satisfactory artificial control measures against *Promecotheca* have been devised. The use of arsenicals, derris, D.D.T., etc., could be undertaken with high-power spraying equipment, but would most likely be uneconomic, except as a drastic measure to thwart an outbreak build-up. In general, it would be safe to assume that chemical treatment would do more harm to parasites than to the beetle. In the case of the build-up of a one-stage outbreak, the ineffectiveness of parasites might justify action.

Some control and purported offsetting of an outbreak has been attributed (Stanley, 1938; Froggatt, 1939) to the burning of infested leaflets by the use of burning oil in half coconut shells attached to the ends of long bamboos, with two ropes attached near the top to control operation from the ground.

STATUS OF POPULATIONS AND OUTBREAKS

To put on record data of possible historical or comparative value, brief sketches are here presented of the status of *Promecotheca* populations and damage at the five principal plantations in New Britain, where I observed *Promecotheca,* during April and May, 1956. Brief observations were also made at the last two in July, 1956, and October, 1957. Linga Linga and Volupai are on the north coast of New Britain, Lindenhafen is on the south coast, and Vunakanau and Taliligap are on the Gazelle Peninsula west of Rabaul Harbour.

Linga Linga

The outbreak, which started in 1953, must have ended in 1955. The effect was still evident in 1956 in copra production, visible gross effect on palms, and in the remaining old mines and adult feeding marks on the older fronds. Thus most of the palm crowns were green above and brown beneath. The beetle population in April, 1956, was exceedingly low, and in the normal multi-stage condition. Very little new evidence of the beetle was found on mature palms. Most of the new eggs, living larvae and adults were found on very young palms, most of which were near the manager's house and No. 1 drier. Four distinct constrictions are seen on many palms, representing four outbreaks. The previously-recorded one was in 1940 - 1941 (Richards), with an earlier one reported in 1923 (Simmonds, 1938). There must have been another one about 1910. Beetles were reported to be abundant in 1933 and gone again by 1935 (Richards). No egg parasites were noted in the few egg-cases seen. Of larval parasites, *Apleurotropis* was more abundant than *Pediobius,* with an apparent ratio of three to one. *Eurytoma* was found in smaller numbers. Ardley (1954) detailed the status of palms near the end of the outbreak.

Volupai

The beetle population at Volupai was larger, in April, 1956, than that at Linga Linga. Again, adults and mines were observed mostly

on very young palms. Only one mature palm was sampled, but this was singled out by plantation workers as particularly infested. It showed considerable activity of some months earlier, with many old mines, old aborted mines, and adult feeding. There had been no noticeable outbreak. There seemed to be no distinct evidence of tendency towards the one-stage condition.

Lindenhafen

The outbreak here, like that of Linga Linga dating from 1953, had ended some months before my visit in April, 1956. Damage here was more complete than at Linga Linga. Copra production was just starting again in 1956, copra being worked every other month. As at Linga Linga and Volupai, *Promecotheca* was multistage, found principally on quite young palms, and as at Linga Linga almost none was found on mature palms, although plenty of evidence of old work remained on lower fronds. The active population was not localized, but spread in most areas with young palms. Often five to 20 adults, and similar numbers of active mines, were found in a single young palm, but they were not present in all of them. A recently-burned area near the manager's house seemed free of the beetle.

PLATE 7.—*Constrictions on coconut palm trunks at Lindenhafen, indicating former outbreak periods.*

The beetle was more abundant at the village, Lulakuni, across the mouth of the stream at the west end of the plantation, but was absent or nearly so on the offshore islands. This was apparently also true during the outbreak.

As at Linga Linga, marks of three outbreaks before the last existed as widely-spaced constrictions on palm trunks (Plate 7). These are not so general as at Linga Linga, but are quite evident in some areas, as near the beach at the point.

Pediobius seemed to be the most abundant parasite. Among submature and mature larvae, and pupae, parasitism was low. There was evidence of moderately high incidence of egg parasitism. The preceding documented outbreak was that of 1936-1938 (Murray, O'Connor). There was also said to have been one in 1928 and possibly one between 1941 and 1945. In December, 1956 (Dun, pers. comm.), a small outbreak in one-stage condition was reported for the first few rows of palms from the beach, both at Lindenhafen and Ring Ring Plantations, with adults up to 100 in number per frond.

Vunakanau

There was a serious outbreak here, with very dense population in limited parts of the plantation (Plate 8), but with very few beetles in other parts. The outbreak was obviously in the one-stage condition when first observed (20th April, 1956, Ardley and Dun ; 2nd May, Gressitt). It was noticed in late 1955, but not reported until April, 1956. In early May there were almost no active mines, but only adults and newly-laid eggs. At the end of May, the situation was not so distinct, as larvae of nearly all ages could be found and even a few pupae and a very few new adult emergence holes. During the month, the adult population fell off very rapidly. This proves that the average lifespan of an adult in the field is much shorter than with caged individuals.

At the end of May it appeared as if the one-stage condition would have to break down rapidly, with new adults emerging and some adults from the previous generation still living.

PLATE 8.—*Badly damaged coconut palms at Vunakanau, Gazelle Peninsula.*

However, the old generation apparently began to die off even more rapidly, and egg-parasitism approached 100 per cent. Far more eggs had been laid on the newest fronds than could possibly develop on them. The beetles were more abundant on mature palms than on young palms. In late April there were a few hundred adult beetles in each of many young palms, while there were a few thousand in each of many infested mature palms, or 200 per frond. Figures for eggs, during May, and mines, at end of May, were analogous. According to Dun (pers. comm.) the damage was more marked in November, 1956, but by then most palms had a few new green fronds, and beetle population was reduced.

The one-stage condition probably terminated early in 1957, and the population had very markedly declined by June, 1957. In December, 1956, many aborted mines were noticed by Dun. In October, 1957, I noted a much reduced population, consisting of all stages, with the population somewhat differently distributed and a little more abundant in young palms at the upper edge of the plantation, near Malmalwan. In January, 1958, Dun noted that, except for some young palms, most palms had revived and were bearing well. Parasitism of larvae and pupae by *Pediobius* was more than 80 per cent. in late April, 1956, and of eggs by *Closterocerus* was fairly high in late May (see Table V). *Apleurotropis* was actively parasitizing young larvae, and *Eurytoma* was scarce.

Taliligap

The outbreak in this small plantation, a short distance from Vunakanau and slightly higher and wetter, was not noticed until May, 1956, during the study at Vunakanau. It was a little behind that of Vunakanau in intensity, but very slightly ahead in chronology of the one-stage condition. New adults appeared earlier at Taliligap and there were more mature mines before end of May. The rate of parasitism seemed slightly lower than at Vunakanau. This might suggest that the infestation started at Vunakanau and spread to Taliligap. However, the beetle's weak spreading potential also suggests that the two outbreaks started independently, from some general climatic change or upset of parasite or predator balance.

On 16th May, 1956, one frond of a 20-year-old palm bore 25 apparently healthy egg-cases, 20 cases with emergence holes of egg-parasites, two cases with hatched eggs, and 55 cases with eggs chewed up by predators, probably ants. Another frond had 36 apparently healthy egg-cases, 12 cases with emergence holes of parasites, three cases hatched and 16 cases chewed by predators. In November, 1956, Dun noted that browning of fronds was more marked, but there was little evidence of nutfall. The outbreak was still one-stage, but most eggs were predated or parasitized. In October, 1957, I noted that the palms looked better, that young palms had some mines, partly aborted, and some new egg-cases.

Other plantations

Witu Island is said to have had an outbreak in 1935 covering 50 hectares, with some nutfall. In 1937, Kabaira Plantation, on the north coast road, Gazelle Peninsula, was affected by the volcanic eruption. One-half the plantation was affected by ashes and this same half suffered from *Promecotheca* from six to nine months

after the eruption. A small localized infestation exists by the road near the manager's house and this population is said to increase every one and a-half to two years. Mandras Plantation, Bainings, Gazelle Peninsula, is said to have had a small outbreak in 1956. Vuvu Plantation, Gazelle Peninsula, had one reported in 1955. Vunakambi Plantation, Gazelle Peninsula, was an area where, during German times, kurukum ants were used to control an outbreak of the beetle. Davuan, Gazelle Peninsula, is said to have had an outbreak in 1936. Bialla Plantation, north-central coast of New Britain, had a moderate outbreak in 1956, involving five per cent. of the plantation, with parasitism increasing rapidly in 1957. Worst-affected parts were near the beach and the wettest part over an underground river.

COPRA PRODUCTION

Reduction of copra production during and following *Promecotheca* outbreaks is conspicuous, although not always borne out clearly from the production statistics. Several factors are involved, such as premature nutfall, which sometimes temporarily increases production, more intense copra-cutting on non-infested off-shore islets or border areas and purchase of trade copra. Dun (1955) reported a 30 per cent. loss of copra production at Linga Linga, and a 50 per cent. loss for Lindenhafen at the start of the last outbreak period. However, as he predicted, the loss later increased.

CLIMATE

The average rainfall (for 17 years) for Lindenhafen is 258.55 inches per year, and for Talasea (near Linga Linga) is 168.28 inches.

TABLE IX.—Rainfall figures (inches) for main New Britain outbreak areas.

	17-year averages		
	Lindenhafen	Talasea (N. coast)	Malmalwan (Gazelle P.)
January	7.31	32.37	10.09
February	6.28	26.68	8.44
March	6.23	24.47	9.91
April	11.18	20.29	10.75
May	26.98	7.93	8.11
June	34.29	5.37	1.08
July	41.68	4.99	5.99
August	46.64	4.90	1.97
September	33.48	4.23	.69
October	21.32	7.26	1.52
November	14.53	8.89	6.95
December	8.63	19.90	8.26
Total annual	258.55	168.28	73.76

For Rabaul it is 89.73 and for Keravat it is 105.76. Vunakanau is between Rabaul and Keravat, but its rainfall is closer to that of Rabaul. In 1955, the rainfall at Malmalwan (very near Vunakanau) was 73.76 inches (see Table IX). This shows that a long, dry period preceded the outbreak at Vunakanau. However, the annual totals for Lindenhafen preceding the serious 1937 outbreak show a long, wet period, as indicated in Table X. Also, as shown in the table, the annual cycle of rainfall at Lindenhafen and Talasea is almost opposite. The 1956 rainfall total for Malmalwan (Vunakanau) was 85.85 inches. The 1957 rainfall was still higher. Humidity is slightly higher at Lindenhafen and Linga Linga than at Vunakanau, but all have a high humidity.

TABLE X.—Annual rainfall (inches) at Lindenhafen preceding 1937 outbreak :—

1934—214.32.

1935—298.62.

1936—268.48.

1937—308.60.

CONCLUSIONS

It is felt that until the main factors contributing to the development of an outbreak are understood, adequate steps to prevent outbreaks cannot be recommended. However, certain precautions, such as the encouragement and protection of lizards, birds, the kurukum ant, and most other ants, should be in order, and may at the same time help to curb other coconut and cacao pests.

Periodical examination of random palms in the plantations for detection of early stages of a developing outbreak could make it possible to effect control before serious damage is done, by using insecticides to kill the adults and cutting down of fronds bearing eggs and mines. It is undesirable to burn fronds bearing eggs or young mines, as the larvae cannot mature when the fronds die, and burning would only result in killing the parasites, most of which would emerge from these stages even after cutting of fronds. Fronds bearing mature mines should be burned or thrown into the sea, unless they can be put in screened containers permitting the escape of parasites but not beetles. Ardley suggested an itinerant extension worker to be on the look-out for incipient outbreaks while visiting plantations.

There is a need for information, which might be obtained during the build-up of an outbreak, to assist in the solution of the general problem.

Knowledge of the other species of *Promecotheca* in the New Guinea-Solomons area might bring to light parasites or predators in nearby areas which might be tried in New Britain to help prevent outbreaks. A better understanding of the general ecology of *Promecotheca papuana* will be required before effecting such introductions. New Guinea is the centre of distribution of the genus *Promecotheca.*

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